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THE ISOLATION AND STUDY OF NITRIFYING BACTERIA

EFFECT OF ALFALFA ON THE FERTILITY ELEMENTS OF THE SOIL IN COMPARISON WITH GRAIN CROPS[1]

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INTRODUCTION

That continuous growing of grain crops decreases the fertility of the soil, and that the growing of legumes in a measure restores this fertility are facts well known to students of soil science. To what degree this takes place is not so well known.

Alfalfa is one of the important crops of Kansas, and was one of the first to be grown. Most of the work concerning the effect of legumes on soil nitrogen has been with red clover and legumes other than alfalfa. This is partly due to the fact that in those states and the countries where investigations have been conducted, alfalfa is not a common crop.

The main problem of the present investigation is this: When alfalfa has been grown continuously on a piece of land, and all the crop harvested as hay, how much nitrogen and organic matter has been added to the soil? Phosphorus and calcium were also included in the study.

There are in Kansas a large number of fields where alfalfa has been grown from 20 to 30 years and near by are others which are still in native sod and also some which have been cropped continuously to grain since the native sod was broken. It was thought that a study of the fertility of the cropped fields as compared with those still in native sod would give valuable information. It will be well to consider first the present status of knowledge on this subject.

HISTORICAL

That native legumes are important sources of nitrogen in the native soil has been shown by several investigators. Warren (10) in a study of the native vegetation of Kansas and Nebraska found that on the average there were 17 native legumes to the square yard. Most of them have enormous root systems. Warren attempted to ascertain the prevalence of nodules on different species and found large numbers on every one. Also he found that the native legumes were more abundant on the poorer soils. This appears

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[1] This work was conducted in cooperation with the Department of Agronomy, and of Division of Extension who rendered valuable service in locating these fields.

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to show that after the legumes have enriched the soil, other plants crowd them out. In pastures the legumes tend to disappear because they are so readily eaten by live stock.

Alway and Pinckney (2) found in four species of native legumes, an average nitrogen content of 2 per cent. They estimated that the natural growth of legumes could furnish 10 pounds of nitrogen per acre annually.

According to Russel, a plat on Broadbalk field, Rothamstead, which was not cropped after 1882, gained 91.7 pounds of nitrogen per acre per annum. This plot contained 3.32 per cent $CaCO_3$. Another plat which contained only 0.16 per cent $CaCO_3$, gained 60 pounds of nitrogen per acre per annum. These amounts are figured to the depth of 27 inches (5). On Doctor Gilbert's meadow which was laid down to grass in 1856, and mowed annually, the amount of nitrogen was doubled in the top 9 inches in a little over 50 years (5).

Russel (4) mentions the classic instance of the restoration of the nitrogen content of the soil of the Schultz-Lupitz estate in Germany as an example, of the power of legumes to restore nitrogen to worn-out soil. This estate was once a barren sand. Lime and fertilizers containing phosphorus and potassium were used but no nitrogenous manures. The land was cropped alternately to lupines and cereals, the former being either plowed under or fed. The barren sand after a time became a rich soil capable of producing a large variety of crops. As shown by Russel the enrichment in nitrogen of soils by legumes is dependent upon available phosphorus and potassium. Thus in experiments at the Rothamstead station there was a large increase in the nitrogen content of soils in which clover was grown in rotation with other crops and to which potash and superphosphates but no nitrogenous manures had been added. There was a loss in nitrogen with the same cropping when no potash or superphosphates were applied. As the experiments were conducted over twenty years the results are no doubt significant.

Shutt (6) found that after 22 years of cultivation a prairie soil of Western Canada had lost a total of 2190 pounds of nitrogen per acre in the top 8 inches. Of this only 700 pounds were contained in the crops removed from the soil. Snyder (7) determined the loss of nitrogen in the soil of a number of typical Minnesota farms in a 10-year period. "The loss from grain farms was from 3 to 5 times the amount removed by the crops. This loss was attributed to the rapid decay of humus and the liberation of nitrogen." The nitrogen content in all these soils was high. Whitson, Stoddart and McLeod (12) collected a number of samples of both cropped and virgin soil from Wisconsin farms. The average nitrogen content of the cropped soil was 0.107 per cent and of the virgin soil 0.170 per cent, showing a loss of over one-third the original stock of nitrogen. These authors also estimated the amount of nitrogen removed by crops and that added by manure and clover. The nitrogen not accounted for by crop removal after correcting for that added in the manure and the clover, was assumed to be lost by leaching and denitrification.

In 6 of the 21 cases, the difference in the amount of nitrogen in the virgin soil and in the cropped soil was not enough to account for the nitrogen which had been removed in the crop. It was suggested that this difference was accounted for by the fixation of nitrogen by soil bacteria. The average amount lost by leaching and denitrification amounted to only 22.3 per cent of that removed by the crops. In clay soils more than four-fifths of the total loss of nitrogen was removed by crops.

In continuing these studies, the authors (13) found that the largest losses of nitrogen occurred in those soils which have a rather large per cent of total nitrogen. In 16 of the 21 cases in which the virgin soil contained 0.2 per cent of nitrogen or over, the loss above that removed by crop exceeded 500 pounds per acre. In 21 of 26 cases where the per cent of nitrogen in the virgin soil was less than 0.2 per cent, the loss was less than 500 pounds per acre. The loss from manured soil was greater than where soils were not manured.

Alway (1) concluded that in the soils of Nebraska, the only constituents that have declined appreciably under cultivation are nitrogen and total organic matter. Whitson and Stoddart (11) found a decrease in the phosphorus content in virgin soil. They found that the average content of phosphoric acid, expressed as P_2O_5 was 0.185 per cent and in nine adjoining cropped soils it was 0.120 per cent, indicating a loss of one-third of the original stock of phosphorus.

It appears that cultivating the soil does not always cause a decrease of nitrogen. Stewart (8) analyzed a number of Utah soils and found an average of 2055 pounds of nitrogen per acre to a depth of 12 inches in soil that had been cropped to wheat, as compared with 2009 pounds in fields that had been cropped to alfalfa and 1984 pounds in virgin soil.

Stewart explains these results by a difference in the composition of the virgin soil, an increase in nitrogen in the cultivated soils due to azotobacter and to a rise of nitrogen from the subsoil by deep roots.

That crop production may be increased after the growth of alfalfa even if the stock of nitrogen has not been materially increased, is shown by an experiment reported by Lyon and Bizzell (3).

Alfalfa and timothy were grown for 6 years on adjoining plats. On plowing up they were planted to corn the first year and oats the second. The yield of corn on the alfalfa plat was 63 bushels per acre, and on the timothy plat 47 bushels per acre. The oats yielded 26 bushels on the alfalfa plat and 27 on the timothy plat. Analyses of the soils from the two plats showed that the alfalfa plat contained not to exceed 0.01 per cent more nitrogen than the soil from the timothy plat. This would amount to 250 pounds per acre if the soil to the depth of 8 inches is assumed to weigh 2,500,000 pounds.

Very little work has been done relating to the effect of legumes on the mineral elements of the soil. Certain work has shown that some elements, particularly phosphorus, have decreased. Other work fails to show any appreciable change. This is partly due to the inherent difficulties of the

TABLE 1

Analysis of soils in virgin sod, fields cropped to alfalfa and of fields cropped to grain in Kansas

LOCATION, COUNTY AND LAND SURVEY	DESCRIPTION, TREATMENT, CHARACTER AND TYPE OF SOIL	STRATUM SAMPLED	LABORATORY NUMBER	PLANT-FOOD ELEMENTS				
				Nitrogen	Phosphorus	Calcium	Organic carbon	Inorganic carbon
		inches		*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Humid section								
Leavenworth County								
N. W. 10 of N. W. 40 of N. E. ¼ Sec. 35. T. 10 S. R. 22 E. of 6 p. m.	Alfalfa 8 years. Blue Grass 10 years before alfalfa. Brown silt loam.	Soil 0–7	1316.1	0.163	0.043	0.530	1.610	
		Subsurface 7–20	1316.2	0.094	0.046	0.480	0.920	
		Subsoil 20–40	1316.3	0.061	0.049	0.640	0.360	
		Subsoil 40–80	1316.4	0.040	0.035	0.610	0.190	0.050
N. E. 10 of S. W. 40 of S. E. ¼ sec. 26. Twp. 10 S. R. 22 E. of 6 p.m.	Cropped to wheat. Well farmed. Brown silt loam.	Soil 0–7	1317.1	0.174	0.048	0.520	1.870	
		Subsurface 7–20	1317.2	0.139	0.041	0.500	1.280	
		Subsoil 20–40	1317.3	0.084	0.034	0.610	0.100	0.070
		Subsoil 40–80	1317.4	0.052	0.044	0.680	0.070	0.040
S. W. 10 of N. E. 40 of N. E. ¼ sec. 15. Twp. 9 S. R. 21 E. of 6 p.m.	Alfalfa 14 years. Before that corn and wheat. Brown silt loam.	Soil 0–7	1318.1	0.222	0.052	0.580	2.500	
		Subsurface 7–20	1318.2	0.177	0.043	0.480	2.180	
		Subsoil 20–40	1318.3	0.121	0.074	0.590	1.640	
		Subsoil 40–80	1318.4	lost				
		Subsoil 80–120	1318.5	0.059	0.042	0.420	0.120	
S. E. 10 of N. E. 40 of N. E. ¼ sec. 5. Twp. 9 S. R. 21 E. of 6 p.m.	Native meadow. Brown silt loam.	Soil 0–7	1319.1	0.296	0.061	0.630	3.760	
		Subsurface 7–20	1319.2	0.225	0.057	0.600	2.540	
		Subsoil 20–40	1319.3	0.144	0.056	0.630	1.120	
		Subsoil 40–80	1319.4	0.082	0.062	0.740	0.260	0.100
		Subsoil 80–100	1319.5	0.085	0.076	0.540	0.200	0.100

Brown County

Location	Description		Depth	Sample No.					
N. E. 10 of N. W. 40 of S. E. ¼ sec. 34. Twp. 1 N. R. 15 E. of 6 p.m.	Alfalfa 28 years. Marshall silt loam.	Soil	0–7	1768.1	0.211	0.063	0.770	2.280	0.770
		Subsurface	7–20	1768.2	0.142	0.055	0.680	1.540	0.680
		Subsoil	20–40	1768.3	0.062	0.059	0.760	0.400	0.760
		Subsoil	40–80	1768.4	0.031	0.066	0.810	0.060	0.810
S. E. 10 of S. E. 40 of S. E. ¼ sec. 28. Twp. 1 N. R. 15 E. of 6 p.m.	White clover and blue grass. Marshall silt loam.	Soil	0–7	1770.1	0.228	0.061	0.620	2.860	
		Subsurface	7–20	1770.2	0.133	0.051	0.610	1.450	
		Subsoil	20–40	1770.3	0.073	0.051	0.710	0.680	
		Subsoil	40–80	1770.4	0.047	0.049	0.710	0.310	
S. W. 10 of S. E. 40 of N. W. ¼ sec. 34. Twp. 1 N. R. 15. E. of 6 p.m.	Continuous grain cropping. Marshall silt loam.	Soil	0–7	1769.1	0.160	0.048	0.610	1.940	
		Subsurface	7–20	1769.2	0.135	0.048	0.660	1.510	
		Subsoil	20–40	1769.3	0.066	0.053	0.710	0.610	
		Subsoil	40–80	1769.4	0.031	0.066	0.860	0.096	

Nemaha County

Location	Description		Depth	Sample No.					
N. W. 10 of S. E. 40 of S. E. ¼ sec. 8. Twp. 5 S. R. 14. E. of 6 p.m.	Alfalfa 21 years. Brown silt loam.	Soil	0–7	1765.1	0.170	0.039	0.660	1.690	0.280
		Subsurface	7–20	1765.2	0.080	0.031	0.700	0.900	
		Subsoil	20–40	1765.3	0.032	0.049	2.000	0.230	
		Subsoil	40–80	1765.4	0.008	0.061	5.280	1.490	
N. W. 10 of S. E. 40 of S. E. ¼ sec. 8. Twp. 5 S. R. 14. E. of 6 p.m.	Cultivated about 45 yrs. Brown silt loam to be compared with 1765.	Soil	0–7	1766.1	0.102	0.040	0.860	1.130	0.030
		Subsurface	7–20	1766.2	0.055	0.044	2.890	0.980	0.620
		Subsoil	20–40	1766.3	0.024	0.050	7.400	1.350	0.960
		Subsoil	40–80	1766.4	0.005	0.059	6.400	0.050	1.650
S. E. 10 of N. E. 40 of N. E. ¼ sec. 17. Twp. 5 E. R. 14. E. of 6 p.m.	Virgin pasture land. Some white clover and blue grass. Brown silt loam.	Soil	0–7	1767.1	0.181	0.038	0.840	1.970	0.050
		Subsurface	7–20	1767.2	0.085	0.042	1.860	0.900	0.240
		Subsoil	20–40	1767.3	0.028	0.049	7.000	0.460	1.940
		Subsoil	40–80	1767.4	0.008	0.058	6.810	0.280	1.680

TABLE 1—Continued

LOCATION, COUNTY AND LAND SURVEY	DESCRIPTION, TREATMENT, CHARACTER AND TYPE OF SOIL	STRATUM SAMPLED (inches)		LABORATORY NUMBER	PLANT-FOOD ELEMENTS				
					Nitrogen per cent	Phosphorus per cent	Calcium per cent	Organic carbon per cent	Inorganic carbon per cent
Montgomery County									
S. E. 10 of S. W. 40 of N. W. ¼ sec. 1. Twp. 33 S. R. 14 E. of 6 p.m.	Alfalfa 13 years. Oswego silt loam.	Soil	0–7	1294.1	0.131	0.036	0.429	2.070	
		Subsurface	7–20	1294.2	0.106	0.022	0.485	1.350	
		Subsoil a	20–40	1294.3	0.054	0.029	0.506	0.800	
		Subsoil b	40–80	1294.4	0.031	0.032	0.712	0.520	0.020
		Subsoil c	80–120	1294.5	0.045	0.051	0.774	0.400	0.030
N. E. 10 of N. W. 40 of S. E. ¼ sec. 1. Twp. 33 S. R. 1. E. of 6 p.m.	Native meadow. Oswego silt loam. To be compared with 1294. This land lies a little lower than 1294 and 1295.	Soil	0–7	1296.1	0.186	0.046	0.580	2.590	
		Subsurface	7–20	1296.2	0.114	0.032	0.630	1.640	
		Subsoil a	20–40	1296.3	0.067	0.037	0.530	0.910	
		Subsoil b	40–72	1296.4	0.024	0.056	0.130	0.350	0.160
S. E. 10 of S. W. 40 of N. W. ¼ sec. 1. Twp. 33 S. R. 14. E. of 6 p.m.	Kaffir, corn, and grain for about 35 years. Oswego silt loam. To be compared with 1294.	Soil	0–7	1295.1	0.110	0.034	0.510	1.730	
		Subsurface	7–20	1295.2	0.094	0.028	0.570	1.250	
		Subsoil a	20–40	1295.3	0.050	0.025	0.640	0.710	0.010
		Subsoil b	40–80	1295.4	0.039	0.022	1.010	0.320	0.110
		Subsoil c	80–120	1295.5	0.049	0.055	0.750	0.260	0.030
S. E. 10 of N. E. 40 of S. E. ¼ sec. 13. Twp. 33 S. R. 16. E. of 6 p.m.	Alfalfa 10 years. Oswego silt loam.	Soil	0–7	1297.1	0.168	0.043	1.410	2.320	0.160
		Subsurface	7–20	1297.2	0.087	0.034	1.190	1.150	0.070
		Subsoil a	20–40	1297.3	0.038	0.023	2.170	0.700	0.430
		Subsoil b	40–72	1297.4	0.028	0.027	1.740	0.460	0.310
S. E. 10 of N. E. 40 of S. E. ¼ sec. 13. Twp. 33 S. R. 16. E. of 6 p.m.	General grain and corn farming. Oswego silt loam. To be compared with 1297.	Soil	0–7	1298.1	0.135	0.038	1.050	2.050	0.060
		Subsurface	7–20	1298.2	0.076	0.016	1.930	1.130	0.290
		Subsoil a	20–40	1298.3	0.043	0.026	2.460	0.700	0.500
		Subsoil b	40–72	1298.4	0.026	0.028	1.330	0.410	0.170

Location	Description	Horizon	No.					
Butler County								0.040
S. E. 10 of S. E. 40 of S. E. ¼ sec. 10. Twp. 25 S. R. 5. E. of 6 p.m.	Corn for over 32 years. Osage silt loam. To be compared with 1897.	Soil 0–7	1896.1	0.139	0.027	0.490	1.540	
		Subsurface 7–20	1896.2	0.117	0.031	0.480	1.240	
		Subsoil a 20–40	1896.3	0.087	0.031	0.500	0.920	
		Subsoil b 40–80	1896.4	0.057	0.032	0.500	0.580	
S. E. 10 of N. E. 40 of S. E. ¼ sec. 10. Twp. 25 S. R. 5. E. of 6 p.m.	Native pasture. Osage silt loam. To be compared with 1897.	Soil 0–7	1898.1	0.196	0.035	0.580	2.350	
		Subsurface 7–20	1898.2	0.132	0.035	0.530	1.400	
		Subsoil a 20–40	1898.3	0.077	0.029	0.540	0.890	
		Subsoil b 40–80	1898.4	0.067	0.026	0.550	0.690	
N. E. 10 of S. E. 40 of S. E. ¼ S. E. sec. 10. Twp. 25. R. 5. E. of 6 p.m.	Corn over 20 years, then Alfalfa about 12 years. Osage silt loam.	Soil 0–7	1897.1	0.161	0.038	0.500	1.710	
		Subsurface 7–20	1897.2	0.118	0.040	0.460	1.130	
		Subsoil a 20–40	1897.3	0.071	0.028	0.460	1.070	
		Subsoil b 40–50	1897.4	0.070	0.030	0.580	0.630	
Chase County								
N. W. 10 of N. E. 40 of S. W. ¼ sec. 14. Twp. 19 S. R. 7. E. of 6 p.m.	Alfalfa about 25 years. Osage loamy silt loam.	Soil 0–7	1900.1	0.201	0.039	0.840	2.230	
		Subsurface 7–20	1900.2	0.129	0.041	0.660	1.530	
		Subsoil a 20–40	1900.3	0.095	0.033	0.510	1.000	
		Subsoil b 40–80	1900.4	0.051	0.034	0.740	0.450	
N. E. 10 of N. W. 40 of S. W. ¼ sec. 14. Twp. 19 S. R. 7. E. of 6 p.m.	Bluestem grass pasture, broken 1 year corn. Osage loamy silt loam.	Soil 0–7	1902.1	0.192	0.050	0.710	2.380	
		Subsurface 7–20	1902.2	0.127	0.036	0.610	1.600	
		Subsoil a 20–40	1902.3	0.067	0.038	0.570	0.680	
		Subsoil b 40–80	1902.4	0.061	0.037	0.560	0.860	
S. W. 10 of N. E. 40 of S. W. ¼ sec. 14. Twp. 19 S. R. 7. E. of 6 p.m.	Corn and wheat 40 years. Osage loamy silt loam.	Soil 0–7	1901.1	0.133	0.042	0.730	1.800	
		Subsurface 7–20	1901.2	0.129	0.049	0.600	1.500	
		Subsoil a 20–40	1901.3	0.109	0.040	0.570	1.490	
		Subsoil b 40–50	1901.4	0.052	0.035	0.550	0.560	
S. E. 10 of N. E. 40 of S. E. ¼ sec. 14. Twp. 19 S. R 7, E. of 6 p.m.	Bluestem meadow. Osage silty clay loam. This soil was recently flooded and covered with 6" silt.	Soil 0–7	1903.1	0.201	0.058	0.780	2.480	
		Subsurface 7–20	1903.2	0.122	0.051	0.720	1.450	
		Subsoil a 20–40	1903.3	0.070	0.036	0.790	0.930	
		Subsoil b 40–90	1903.4	0.038	0.039	0.810	0.530	

TABLE 1—*Continued*

LOCATION, COUNTY AND LAND SURVEY	DESCRIPTION, TREATMENT, CHARACTER AND TYPE OF SOIL	STRATUM SAMPLED *inches*	LABORATORY NUMBER	PLANT-FOOD ELEMENT				
				Nitrogen *per cent*	Phosphorus *per cent*	Calcium *per cent*	Organic carbon *per cent*	Inorganic carbon *per cent*
Harvey County								
S. E. 10 of N. E. 40 of N. W. ¼ sec. 23. Twp. 24 S. R. 2 W. of 6 p.m.	Wheat and corn about 14 years then alfalfa 11 years. Dark gray fine sandy loam.	Soil 0–7 / Subsurface 7–20 / Subsoil a 20–40 / Subsoil b 40–80	1890.1 / 1890.2 / 1890.3 / 1890.4	0.161 / 0.087 / 0.045 / 0.036	0.041 / 0.032 / 0.023 / 0.055	0.570 / 0.450 / 0.400 / 0.300	1.910 / 0.720 / 0.410 / 0.160	0.050
S. E. 10 of N. E. 40 of N. W. ¼ sec. 23. Twp. 24 S. R. 2 W. of 6 p.m.	Native bluestem pasture. Fine sandy loam. To be compared with 1890.	Soil 0–7 / Subsurface 7–20 / Subsoil a 20–40 / Subsoil b 40–80	1891.1 / 1891.2 / 1891.3 / 1891.4	0.189 / 0.101 / 0.049 / 0.029	0.056 / 0.033 / 0.026 / 0.026	0.470 / 0.350 / 0.460 / 0.400	2.280 / 1.010 / 0.400 / 0.060	
S. W. 10 of N. W. 40 of N. W. ¼ sec. 23. Twp. 24 S. R. 2. W. of 6 p.m.	Wheat and corn 25 years. Fine sandy loam. To be compared with 1890.	Soil 0–7 / Subsurface 7–20 / Subsoil a 20–40 / Subsoil b 40–80	1892.1 / 1892.2 / 1892.3 / 1892.4	0.140 / 0.107 / 0.072 / 0.056	0.053 / 0.045 / 0.043 / 0.032	0.600 / 0.670 / 0.560 / 0.560	1.120 / 0.980 / 0.490 / 0.410	
S. W. 10 of S. E. 40 of S. E. ¼ sec. 2. Twp. 22 S. R. 2. W. of 6 p.m.	Corn and wheat 30 years, then alfalfa 14 years. Heavy silt loam.	Soil 0–7 / Subsurface 7–20 / Subsoil 20–36	1893.1 / 1893.2 / 1893.3	0.200 / 0.097 / 0.075	0.043 / 0.034 / 0.029	0.530 / 0.720 / 1.300	2.310 / 1.630 / 0.800	0.060
N. W. 10 of S. E. 40 of S. E. ¼ sec. 2. Twp. 22 S. R. 2. W. of 6 p.m.	Native pasture. Heavy silt loam.	Soil 0–7 / Subsurface 7–20 / Subsoil 20–40	1894.1 / 1894.2 / 1894.3	0.222 / 0.122 / 0.057	0.045 / 0.047 / 0.046	0.620 / 0.740 / 1.030	2.660 / 1.370 / 0.790	0.030
S. E. 10 of the N. W. 40 of S. E. ¼ sec. 2. Twp. 22 S. R. 2. W. of 6 p.m.	Farmed to corn and wheat. Heavy silt loam.	Soil 0–7 / Subsurface 7–20 / Subsoil 20–40	1895.1 / 1895.2 / 1895.3	0.124 / 0.099 / 0.062	0.036 / 0.036 / 0.048	0.570 / 0.680 / 0.990	1.230 / 0.980 / 0.500	0.070

Location	Description	Horizon	Depth	No.					
Dickinson County S. E. 10 of S. E. 40 of N. W. ¼ sec. 30. Twp. 12 S. R. 4. E. of 6 p.m.	Alfalfa 15 to 20 years. Osage silt loam.	Soil Subsurface Subsoil a Subsoil b	0–7 7–20 20–40 40–80	1874.1 1874.2 1874.3 1874.4	0.168 0.117 0.084 0.051	0.048 0.045 0.047 0.050	0.730 0.780 0.980 1.960	1.820 1.200 0.854 0.350	0.0090 0.0059 0.2000
N. E. 10 of S. E. 40 of S. E. ¼ sec. 19. Twp. 12 S. R. 4. E. of 6 p.m.	Native bluestem. Osage loam. To be compared with 1874.	Soil Subsurface Subsoil a Subsoil b	0–7 7–20 20–40 40–80	1876.1 1876.2 1876.3 1876.4	0.204 0.134 0.109 0.062	0.048 0.042 0.041 0.042	0.940 0.760 0.880 1.020	2.460 1.610 1.120 0.360	0.0059
S. W. 10 of S. W. 40 of N. W. ¼ sec. 29. Twp. 12 S. R. 4. E. of 6 p.m.	Farmed to grains, mostly corn for 33 years. Osage silt loam. To be compared with 1874.	Soil Subsurface Subsoil a Subsoil b	0–7 7–20 20–40 40–80	1875.1 1875.2 1875.3 1875.4	0.140 0.101 0.084 0.062	0.057 0.047 0.062 0.063	1.060 1.070 1.570 2.000	1.820 1.070 0.960 0.940	0.0200 0.0046 0.0600 0.2600
N. E. 10 of N. W. 40 of N. E. ¼ sec. 8. Twp. 12 S. R. 4. E. of 6 p.m.	Alfalfa 15–20 years. Brown silt loam.	Soil Subsurface Subsoil a Subsoil b	0–7 7–20 20–40 40–80	1877.1 1877.2 1877.3 1877.4	0.179 0.134 0.077 0.060	0.044 0.037 0.040 0.044	0.880 0.980 0.940 1.060	2.000 1.260 0.795 0.320	0.0046 0.0400
N. W. 10 of N. E. 40 of N. E. ¼ sec. 8. Twp. 12 S. R. 4. E. of 6 p.m.	Native pasture. Dark brown silt loam. To be compared with 1877.	Soil Subsurface Subsoil Subsoil	0–7 7–20 20–40 40–80	1879.1 1879.2 1879.3 1879.4	0.204 0.131 0.080 0.066	0.061 0.043 0.040 0.046	0.890 0.890 1.040 0.930	2.630 1.430 0.750 0.680	0.0400
S. E. 10 of N. W. 40 of N. E. ¼ sec. 8. Twp. 12 S. R. 4. E. of 6 p.m.	Corn, wheat, oats for 40 years. Brown silt loam. To be compared with 1877.	Soil Subsurface Subsoil a Subsoil b	0–7 7–20 20–40 40–80	1878.1 1878.2 1878.3 1878.4	0.163 0.120 0.070 0.069	0.048 0.046 0.041 0.041	0.970 1.010 1.220 0.910	2.006 1.185 0.640 0.380	0.0036 0.0046 0.0400 0.0068

TABLE 1—*Continued*

LOCATION, COUNTY AND LAND SURVEY	DESCRIPTION, TREATMENT, CHARACTER AND TYPE OF SOIL	STRATUM SAMPLED		LABORATORY NUMBER	PLANT-FOOD ELEMENTS				
			inches		Nitrogen	Phosphorus	Calcium	Organic carbon	Inorganic carbon
					per cent	*per cent*	*per cent*	*per cent*	*per cent*
Dickinson County—Continued									
S. E. 10 of S. E. 40 of S. E. ¼ sec. Twp. 14 S. R. 3. E. of 6 p.m.	Alfalfa 25 years. Broken 3 years. Reseeded to alfalfa. Dark gray silty clay loam. This was at times pastured by hogs.	Soil	0–7	1880.1	0.201	0.091	0.890	2.510	
		Subsurface	7–20	1880.2	0.130	0.043	0.970	1.470	
		Subsoil a	20–40	1880.3	0.083	0.037	1.220	0.770	0.0200
		Subsoil b	40–80	1880.4	0.066	0.041	1.170	0.637	0.0027
N. E. 10 of N. E. 40 of N. E. ¼ sec. 24. Twp. 14 S. R. 3. E. of 6 p.m.	Native bluestem pasture. Dark gray, silty clay loam. To be compared with 1880.	Soil	0–7	1881.1	0.209	0.087	0.920	3.030	
		Subsurface	7–20	1881.2	0.136	0.042	0.990	1.490	
		Subsoil	20–40	1881.3	0.081	0.038	1.040	0.830	0.030
		Subsoil	40–80	1881.4	0.050	0.045	1.220	0.260	0.130
S. W. 10 of S. W. 40 of N. W. ¼ sec. 18. Twp. 14 S. R. 4. E. of 6 p.m.	Farmed mostly to wheat, some corn and kafir, for 35 years. Dark gray silty clay loam. To be compared with 1880.	Soil	0–7	1883.1	0.155	0.045	0.890	2.060	
		Subsurface	7–20	1883.2	0.123	0.038	0.860	1.590	
		Subsoil a	20–40	1883.3	0.082	0.040	0.920	0.840	
		Subsoil b	40–80	1883.4	0.061	0.037	0.920	0.500	
S. E. 10 of S. E. 40 of N. E. ¼ sec. 13. Twp. 14 S. R. 3. E. of 6 p.m.	Alfalfa about 5 years. Dark gray, probably Summit silty clay loam.	Soil	0–7	1882.1	0.157	0.052	0.840	2.270	
		Subsurface	7–20	1882.2	0.113	0.051	0.920	1.400	
		Subsoil	20–40	1882.3	0.081	0.048	1.040	0.840	

Mitchell County		Sub-humid section							
S. W. 10 of the N. E. 40 of N. W. ¼ Sec. 20, Twp. 7 S. R. 6. W. of 6 P.M.	Alfalfa 24 years, very dark gray silty, clay loam; bottom land.	Soil	0–7	1771.1	0.204	0.075	3.180	2.420	0.470
		Subsurface	7–20	1771.2	0.098	0.068	3.910	1.170	0.660
		Subsoil a	20–40	1771.3	0.034	0.050	5.580	0.810	0.980
		Subsoil b	40–80	1771.4	0.020	0.053	4.680	1.190	0.096
S. E. 10 of the N. W. 40 of N. E. ¼ sec. 20, Twp. 7 S. R. 6. W. of 6 P.M.	Corn and wheat mostly corn for 30 years, very dark gray, silty clay loam, bottom land.	Soil	0–7	1772.1	0.180	0.072	2.290	2.180	0.270
		Subsurface	7–20	1772.2	0.093	0.055	4.320	1.010	0.910
		Subsoil a	20–40	1772.3	0.033	0.063	5.680	0.500	1.270
		Subsoil b	40–80	1772.4	0.017	0.054	5.170	0.200	1.140
S. W. 10 of the S. E. 40 of N. E. ¼ Sec. 20, Twp. 7 S. R. 6. W. of 6 P.M.	Native pasture, gray on dark yellow; a loam soil; upland.	Soil	0–7	1773.1	0.238	0.063	1.400	3.140	0.048
		Subsurface	7–20	1773.2	0.140	0.062	1.750	1.590	0.140
		Subsoil a	20–40	1773.3	0.067	0.056	4.350	0.790	0.930
		Subsoil b	40–80	1773.4	0.062	0.045	2.300	0.390	0.340
S. E. 10 of the S. W. 40 of N. E. ¼ Sec. 20, Twp. 7, S. R. 6. W. of 6 P.M.	Alfalfa 26 years, gray on dark yellow; a loam soil; upland.	Soil	0–7	1774.1	0.269	0.069	2.380	3.230	0.310
		Subsurface	7–20	1774.2	0.101	0.059	5.930	1.390	1.530
		Subsoil a	20–40	1774.3	0.090	0.059	4.150	1.290	0.850
		Subsoil b	40–80	1774.4	0.045	0.057	3.550	0.440	0.750
In center of 10 of the N. E. 40 of N.W. ¼ Sec. 21, Twp. 7 S. R. 6. W. of 6 P.M.	Native pasture, gray on yellow, silt loam; upland. Compare with 1775.	Soil	0–7	1776.1	0.290	0.105	3.370	2.890	0.380
		Subsurface	7–20	1776.2	0.119	0.083	4.900	1.420	1.110
In center of N. E. 40 of N. W. ¼ Sec. 21, Twp. 7 S. R. 6 W. of 6 P.M.	Corn and wheat 23 years, gray on yellow, a silt loam; upland.	Soil	0–7	1775.1	0.186	0.096	4.000	2.090	0.790
		Subsurface	7–20	1775.2	0.084	0.071	4.090	1.060	0.920

TABLE 1—Continued

LOCATION, COUNTY AND LAND SURVEY	DESCRIPTION, TREATMENT, CHARACTER AND TYPE OF SOIL	STRATUM SAMPLED		LABORATORY NUMBER	PLANT-FOOD ELEMENTS				
			inches		Nitrogen	Phosphorus	Calcium	Organic carbon	Inorganic carbon
					per cent	per cent	per cent	per cent	per cent
Mitchell County—Continued									
N. E. 10 of the N. W. 40 of S. E. ¼ Sec. 6, Twp. 6 S. R. 10. W. of 6 P.M.	Alfalfa 23 years, gray, Lincoln silt loam, bottom land.	Soil	0–7	1779.1	0.160	0.079	1.300	1.260	0.070
		Subsurface	7–20	1779.2	0.068	0.059	3.260	0.830	0.590
		Subsoil a	20–40	1779.3	0.062	0.058	2.610	0.730	0.400
		Subsoil b	40–72	1779.4	0.048	0.066	1.200	0.630	0.080
S. E. 10 of the N. W. 40 of N. W. ¼ Sec. 6, Twp. 6 S. R. 10. W. of 6 P.M.	Native pasture, gray Lincoln silt loam; bottom land. Compare with 1779.	Soil	0–7	1778.1	0.180	0.068	1.030	1.870	0.040
		Subsurface	7–20	1778.2	0.069	0.056	2.180	0.750	0.380
		Subsoil a	20–40	1778.3	0.048	0.066	1.650	0.390	0.130
		Subsoil b	40–80	1778.4	0.026	0.065	2.710	0.260	0.120
S. E. 10 of the N. W. 40 of N. W. ¼ Sec. 6, Twp. 6 S. R. 10. W. of 6 P.M.	Corn and wheat 30 years gray Lincoln silt loam, bottom land. Compare with 1778.	Soil	0–7	1777.1	0.129	0.065	1.500	1.420	0.120
		Subsurface	7–20	1777.2	0.058	0.060	3.130	0.670	0.670
		Subsoil a	20–40	1777.3	0.069	0.064	2.830	0.360	0.490
		Subsoil b	40–80	1777.4	0.064	0.064	1.800	0.950	0.150
S. W. 10 of N. W. 40 of N. W. ¼ Sec. 6, Twp. 6 S. R. 10. W. of 6 P.M.	Wheat and corn 30 years, gray on yellow, silt loam, upland.	Soil	0–7	1781.1	0.115	0.057	0.950	1.340	
		Subsurface	7–20	1781.2	0.046	0.071	2.690	1.230	
N. E. 10 of N. E. 40 of S. E. ¼ Sec. 1, Twp. 6 S. R. 11. W. of 6 P.M.	Native pasture yellow on gray, silt loam, upland.	Soil	0–7	1780.1	0.153	0.055	0.950	1.780	
		Subsurface	7–20	1780.2	0.082	0.058	0.950	0.920	

Osborne County

Location	Description	Soil	Depth	Number					
N. W. 40 of the S. W. ¼ Sec. 1, Twp. 8 S. R. 13. W. of 6 P.M.	Alfalfa 20 years, dark gray Lincoln silt loam. The soil had been plowed the spring before sampling.	Soil	0–7	1783.1	0.184	0.060	1.100	2.300	0.080
		Subsurface	7–20	1783.2	0.101	0.059	1.400	1.350	0.060
		Subsoil a	20–40	1783.3	0.062	0.060	1.300	0.660	0.090
		Subsoil b	40–80	1783.4	0.039	0.060	1.400	0.360	
S. E. 40 of the S. W. ¼ Sec. 1, Twp. 8 S. R. 13. W. of 6 P.M.	Native pasture, dark gray Lincoln silt loam.	Soil	0–7	1784.1	0.250	0.068	1.100	3.220	0.090
		Subsurface	7–20	1784.2	0.120	0.063	1.250	1.610	0.560
		Subsoil a	20–40	1784.3	0.066	0.066	3.030	0.780	0.560
		Subsoil b	40–80	1784.4	0.038	0.076	2.950	0.510	
N. W. 40 of the N. W. ¼ Sec. 12, Twp. 8 S. R. 13. W. of 6 P.M.	Farmed to corn and wheat 40 years, dark gray Lincoln silt loam.	Soil	0–7	1782.1	0.134	0.067	1.050	1.660	0.120
		Subsurface	7–20	1782.2	0.096	0.066	1.500	1.250	0.840
		Subsoil a	20–40	1782.3	0.050	0.068	3.910	0.530	0.760
		Subsoil b	40–80	1782.4	0.033	0.067	3.810	0.540	
N. E. 40 of the N. E. ¼ Sec. 12, Twp. 8 S. R. 13. W. of 6 P.M.	Native pasture and meadow, type same as 1785.	Soil	0–7	1786.1	0.232	0.106	1.200	3.710	0.070
		Subsurface	7–20	1786.2	0.120	0.071	1.200	1.440	0.058
N. E. 40 of the N. E. ¼ Sec. 13, Twp. 8 S. R. 13. W. of 6 P.M.	Wheat and corn for 35 years, dark gray, heavy upland soil.	Soil	0–7	1785.1	0.211	0.103	1.350	2.650	0.050
		Subsurface	7–20	1785.2	0.149	0.080	1.150	1.730	0.050
N.W. 40 of S.W. ¼ Sec. 9, Twp. 6 S. R. 13. W. of 6 P.M.	Alfalfa 33 years dark gray Lincoln silt loam.	Soil	0–7	1787.1	0.196	0.070	2.200	2.220	0.320
		Subsurface	7–20	1787.2	0.095	0.085	3.510	1.330	0.650
		Subsoil	20–40	1787.3	0.084	0.077	2.100	1.180	0.280
N. W. 40 of the S. W. ¼ Sec. 9, Twp. 6 S. R. 13. W. of 6 P.M.	Native timber, otherwise the same as 1787.	Soil	0–7	1789.1	0.220	0.100	2.030	3.110	0.240
		Subsurface	7–20	1789.2	0.115	0.098	2.780	1.340	0.520
		Subsoil	20–36	1789.3	0.092	0.087	3.830	1.090	0.890
N. E. 40 of S. W. ¼ Sec. 9, Twp. 6 S. R. 13. W. of 6 P.M.	Corn and wheat for 35 years, otherwise same as 1787.	Soil	0–7	1788.1	0.143	0.090	2.330	1.770	0.350
		Subsurface	7–20	1788.2	0.078	0.084	3.580	1.020	0.680
		Subsoil	20–40	1788.3	0.046	0.090	4.290	0.650	0.930

TABLE 1—Continued

LOCATION, COUNTY AND LAND SURVEY	DESCRIPTION, TREATMENT, CHARACTER AND TYPE OF SOIL	STRATUM SAMPLED (inches)	LABORATORY NUMBER	PLANT-FOOD ELEMENTS				
				Nitrogen per cent	Phosphorus per cent	Calcium per cent	Organic carbon per cent	Inorganic carbon per cent
Barton County								
N. E. 10 of S. W. 40 of N. E. ¼ Sec. 17, Twp. 20 S. R. 13 W. of 6 P. M.	Alfalfa 15 years before that wheat and corn 15 years, dark gray Greensburg sandy loam.	Soil 0–7	1884.1	0.159	0.054	0.580	1.910	
		Subsurface 7–20	1884.2	0.058	0.054	0.730	0.570	
		Subsoil a 20–40	1884.3	0.037	0.051	1.340	0.480	0.170
		Subsoil b 40–80	1884.4	0.029	0.048	5.900	0.760	1.470
N. E. 10 of S. W. 40 of N. E. ¼ Sec. 17, Twp. 20 S. R. 13 W. of 6 P. M.	Buffalo grass pasture, dark Greensburg sandy loam.	Soil 0–7	1885.1	0.106	0.052	0.720	1.280	0.040
		Subsurface 7–20	1885.2	0.050	0.033	0.940	0.390	0.070
		Subsoil a 20–40	1885.3	0.028	0.057	0.950	0.200	0.070
		Subsoil b 40–80	1885.4	0.021	0.041	5.580	0.130	1.370
S. E. 10 of S. W. 40 of N. E. ¼ Sec. 17, Twp. 20 S. R. 13 W. of 6 P. M.	Wheat and corn 30 years, dark gray Greensburg sandy loam.	Soil 0–7	1886.1	0.137	0.047	1.030	1.680	0.030
		Subsurface 7–20	1886.2	0.076	0.052	1.040	0.940	0.030
		Subsoil a 20–40	1886.3	0.038	0.050	4.230	0.660	1.020
		Subsoil b 40–80	1886.4	0.022	0.042	21.500	0.750	5.930
Pawnee County								
S. E. 10 of N. W. 40 of N. W. ¼ Sec. 7, Twp. 22 S. R. 16 W. of 6 P. M.	Alfalfa 28 years, dark gray Arkansas fine sandy loam.	Soil 0–7	1887.1	0.221	0.053	1.200	2.560	0.070
		Subsurface 7–20	1887.2	0.122	0.052	1.640	1.610	0.150
		Subsoil a 20–40	1887.3	0.059	0.059	4.37	1.150	0.990
		Subsoil b 40–80	1887.4	0.017	0.058	3.860	0.420	0.870

Location	Description	Layer	Depth	No.					
S. E. 10 of N. W. 40 of N. W. ¼ Sec. 7. Twp. 22 S. R. 16 W. of 6 P. M.	Buffalo pasture, dark gray Arkansas fine sandy loam.	Soil	0–7	1888.1	0.214	0.059	1.000	2.530	
		Subsurface	7–20	1888.2	0.106	0.046	0.910	0.940	
		Subsoil a	20–40	1888.3	0.053	0.053	2.570	0.570	0.280
		Subsoil b	40–80	1888.4	0.014	0.054	2.820	0.280	0.700
S. E. 10 of S. W. 40 of S. W. ¼ Sec. 6, Twp. 22 S. R. 16 W. of 6 P. M.	Wheat, corn and kafir, 20 years, dark gray Arkansas fine sandy loam.	Soil	0–7	1889.1	0.201	0.093	0.950	2.110	0.005
		Subsurface	7–20	1889.2	0.113	0.058	0.980	1.390	0.051
		Subsoil a	20–40	1889.3	0.072	0.055	3.800	0.540	1.020
		Subsoil b	40–80	1889.4	0.060	0.058	4.640	1.010	1.020

Semi-arid section

Ford County

Location	Description	Layer	Depth	No.					
—10 of the S. E. 40 of S. W. ¼ Sec. 27, Twp. 26 S. R. 25 W. of 6 P. M.	Alfalfa 30 years, dark brown silt loam.	Soil	0–7	1310.1	0.210	0.082	1.710	2.080	0.260
		Subsurface	7–20	1310.2	0.085	0.058	2.660	0.610	0.550
		Subsoil a	20–40	1310.3	0.069	0.058	2.710	0.330	0.680
		Subsoil b	40–80	1310.4	0.075	0.044	1.970	0.600	0.290
		Subsoil c	80–120	1310.5	0.046	0.055	2.080	0.290	0.370
—10 of the S. E. 40 of S. W. ¼ Sec. 27, Twp. 26 S. R. 25 W. of 6 P. M.	Native sod. Compare with 1310.	Soil	0–7	1311.1	*0.171*	0.079	1.580	*3.600*	0.160
		Subsurface	7–20	1311.2	0.108	0.033	1.930	0.970	0.300
		Subsoil a	20–40	1311.2	0.061	0.043	2.300	0.540	0.500
		Subsoil b	40–80	1311.4	0.073	0.058	1.780	0.770	0.120
		Subsoil c	80–120	1311.5	0.039	0.040	2.440	0.250	0.430
—10 of the S. E. 40 of S. W. ¼ Sec. 27, Twp. 26 S. R. 25 W. of 6 P. M.	Cultivated 30 years, principally forage crops. Compare with 1310.	Soil	0–7	1312.1	0.136	0.075	1.980	1.820	0.280
		Subsurface	7–20	1312.2	0.079	0.056	2.870	0.910	0.560
		Subsoil a	20–40	1312.3	0.057	0.064	2.450	0.860	0.420
		Subsoil b	40–80	1312.4	0.055	0.055	2.410	0.620	0.500
		Subsoil c	80–120	1312.5	0.051	0.052	1.920	0.480	0.340

TABLE 1—Continued

LOCATION, COUNTY AND LAND SURVEY	DESCRIPTION, TREATMENT, CHARACTER AND TYPE OF SOIL	STRATUM SAMPLED	LABORATORY NUMBER	PLANT-FOOD ELEMENTS				
				Nitrogen	Phosphorus	Calcium	Organic carbon	Inorganic carbon
		inches		*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Ford County—Continued								
N. W. 10 of the N. E. 40 of N. E. ¼ Sec. 36, Twp. 25 S. R 25 W. of 6 P. M.	Alfalfa 10 years. Richland silt loam.	Soil 0–7	1313.1	0.156	0.082	0.970	1.660	
		Subsurface 7–20	1313.2	0.051	0.030	2.150	0.990	0.400
S. W. 10 of S. E. 40 of S. E. ¼ Sec. 25, S. R. 25 W. of 6 P. M.	Native pasture, dark gray. Compare with 1313.	Soil 0–7	1315.1	0.152	0.043	0.930	1.740	
		Subsurface 7–20	1315.2	0.089			0.690	0.060
N. W. 10 of the N. E. 40 of N. E. ¼ Sec. 36, Twp. 25 S. R 25 W. of 6 P. M.	Cultivated 30 years. Compare with 1313.	Soil 0–7	1314.1	0.118	0.063	0.890	1.480	0.080
		Subsurface 7–20	1314.2	0.085	0.057	1.710	0.650	0.280
Finney County								
N. E. 10 of the N. E. 40 of S. E. ¼ Sec. 9, Twp. 22, S. R. 33 W. of 6 P. M.	Alfalfa, 20 years. Richland silt loam.	Soil 0–7	1299.1	0.168	0.076	0.930	1.610	0.142
		Subsurface 7–20	1299.2	0.085	0.066	1.340	0.698	
		Subsoil a 20–40	1299.3	0.047	0.054	6.030	0.498	1.282
		Subsoil b 40–80	1299.4	0.040	0.062	4.150	0.707	0.913
N. W. 10 of the N. W. 40 of S. W. ¼ Sec. 10, Twp. 22, S. R. 33 W. of 6 P. M.	Native range, Richland silt loam. Compare with 1299.	Soil 0–7	1300.1	0.137	0.077	0.920	1.940	0.380
		Subsurface 7–20	1300.2	0.084	0.063	1.990	0.460	0.980
		Subsoil a 20–40	1300.3	0.038	0.056	5.670	0.300	0.720
		Subsoil b 40–80	1300.4	0.048	0.076	3.660	0.610	
S. W. 10 of the S. W. 40 of S. W. ¼ Sec. 26, Twp. 23 S. R. 33 W. of 6 P. M.	Farmed to wheat, sorghum and kafir, 20 years. Richland silt loam. Compare with 1303.	Soil 0–7	1301.1	0.134	0.070	1.500	1.760	0.160
		Subsurface 7–20	1301.2	0.101	0.073	3.600	0.750	0.830
		Subsoil a 20–40	1301.3	0.058	0.064	5.350	0.540	1.200
		Subsoil b 40–80	1301.4	0.033	0.089	3.500	0.370	0.840
		Subsoil c 80–120	1301.5	0.028	0.076	2.730	0.430	0.530

Location	Description	Soil	Depth	Sample					
N. E. 10 of the S. W. 40 of S. W. ¼ Sec. 26, Twp. 23, R. 33, W. of 6 P. M.	Alfalfa 27 years. Richland silt loam.	Soil	0–7	1303.1	0.200	0.085	3.030	1.930	0.680
		Subsurface	7–20	1303.2	0.113	0.062	1.680	1.030	0.250
		Subsoil a	20–40	1303.3	0.067	0.067	5.500	0.790	0.970
		Subsoil b	40–80	1303.4	0.035	0.061	4.280	0.490	0.920
		Subsoil c	80–120	1303.5	0.015	0.065	3.000	0.160	0.560
N. W. 10 of the N. W. 40 of N. W. ¼ Sec. 36, Twp. 23 S. R. 33 W. of 6 P. M.	Native Buffalo grass. Richland silt loam. Compare with 1303.	Soil	0–7	1302.1	0.135	0.082	0.990	1.680	0.048
		Subsurface	7–20	1302.2	0.086	0.061	2.090	0.670	0.340
		Subsoil a	20–40	1302.3	0.050	0.055	2.900	0.470	0.600
		Subsoil b	40–80	1302.4	0.034	0.084	1.630	0.130	0.160
		Subsoil c	80–120	1302.5	0.028	0.063	1.200	0.050	0.050
N. W. 10 of the N. E. 40 of N. W. ¼ Sec. 11, Twp. 24 S. R. 33 W. of 6 P. M.	Alfalfa 27 years, Laurel sandy loam.	Soil	0–7	1304.1	0.178	0.064	1.070	1.720	0.300
		Subsurface	7–20	1304.2	0.080	0.052	2.930	0.760	1.240
		Subsoil a	20–40	1304.3	0.048	0.036	5.880	0.790	0.420
		Subsoil b	40–80	1304.4	0.020	0.041	2.140	0.540	
S. E. 10 of the S. W. 40 of S. W. ¼ Sec. 12, Twp. 24 S. R. 33 W. of 6 P.M.	Farmed about 27 years. Laurel sandy loam. Compare with 1304.	Soil	0–7	1305.1	0.079	0.053	1.290	1.040	0.710
		Subsurface	7–20	1305.2	0.057	0.048	1.400	0.690	0.200
		Subsoil a	20–40	1305.3	0.039	0.043	3.540	0.750	0.690
		Subsoil b	40–80	1305.4	0.012	0.040	1.750	0.390	0.380
N. W. 10 of the N. W. 40 of S. E. ¼ Sec. 7, Twp. 24 S. R. 32, W. of 6 P. M.	Alfalfa for 30 years, Finney sandy loam.	Soil	0–7	1306.1	0.192	0.078	3.170	2.040	0.680
		Subsurface	7–20	1306.2	0.082	0.041	1.520	0.830	0.230
		Subsoil a	20–40	1306.3	0.040	0.060	3.480	0.670	0.630
		Subsoil b	40–72	1306.4	0.010	0.043	1.350	0.100	0.290
N. W. 10 of the S. E. 40 of S. E. ¼ Sec. 7, Twp. 24, R. 32 W. of 6 P. M.	Native Buffalo grass pasture, laurel loam. Compare with 1306.	Soil	0–7	1308.1	0.099	0.068	0.980	0.890	0.070
		Subsurface	7–20	1308.2	0.052	0.052	2.810	0.300	0.620
		Subsoil a	20–40	1308.3	0.048	0.058	5.180	0.370	1.200
		Subsoil b	40–60	1308.4	0.028	0.039	5.400	0.230	1.510
N. W. 10 of the N. W. 40 of S. E. ¼ Sec. 7, Twp. 24 S. R. 32 W. of 6 P. M.	Sorghum, kafir and small grain for 30 years. Finney sandy loam. Compare with 1306.	Soil	0–7	1307.1	0.097	0.062	1.310	0.980	0.100
		Subsurface	7–20	1307.2	0.066	0.050	3.280	0.680	0.730
		Subsoil a	20–40	1307.3	0.036	0.063	5.780	0.920	1.320
		Subsoil b	40–72	1307.4	0.010	0.044	0.740	0.020	0.120

TABLE 1—*Continued*

LOCATION, COUNTY AND LAND SURVEY	DESCRIPTION, TREATMENT, CHARACTER AND TYPE OF SOIL	STRATUM SAMPLED	LABORATORY NUMBER	PLANT-FOOD ELEMENTS				
				Nitrogen	Phosphorus	Calcium	Organic carbon	Inorganic carbon
		inches		*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Finney County—Continued								
S. E. 10 of the N. E. 40 of the S.E. ¼ Sec. 15. Twp. 24 S. R. 33. W. of 6 P.M.	Alfalfa for 15 years, dark brown, very shallow, Laurel sandy loam.	Soil 0–7	1309.1	0.166	0.075	2.350	1.600	0.450
		Subsurface 7–20	1309.2	0.066	0.049	2.480	0.540	0.670
		Subsoil 20–36	1309.3	0.028	0.045	2.450	0.120	0.580
Gove County								
N. E. ¼ Sec. 29. Twp. 11, R. 26	Native pasture, Grama and Buffalo grass, Colby silt loam.	Soil 0–7	1797.1	0.154	0.084	1.080	1.840	
		Subsurface 7–20	1797.2	0.077	0.094	1.050	0.750	
N. E. ¼ Sec. 29. Twp. 11, R. 26.	Farmed 30 years, mostly wheat, Colby silt loam. Compare with 1797.	Soil 0–7	1796.1	0.128	0.105	1.000	1.350	
		Subsurface 7–20	1796.2	0.070	0.082	1.300	0.670	
N. W. 10 of the S. E. 40 of N. E. ¼ Sec. 12, Twp. 13 S. R. 28 W. of 6 P.M.	Buffalo grass, then alfalfa 15 years, loam bottom land.	Soil 0–7	1798.1	0.210	0.100	1.830	2.230	0.100
		Subsurface 7–20	1798.2	0.086	0.078	2.200	0.900	0.300
		Subsoil a 20–40	1798.3	0.039	0.082	3.560	0.400	0.830
		Subsoil b 40–72	1798.4	0.021	0.097	3.810	0.130	0.860
S. W. 10 of the S. E. 40 of N. E. ¼ Sec. 12, Twp. 13, S. R. 28, W. of 6 P.M.	Native grass, loam bottom land. Compare with 1798. This land was burned over occasionally.	Soil 0–7	1799.1	0.188	0.086	2.000	2.160	0.200
		Subsurface 7–20	1799.2	0.056	0.084	3.110	0.650	0.550
		Subsoil a 20–40	1799.3	0.036	0.077	3.110	0.300	0.670
		Subsoil b 40–72	1799.4	0.015	0.069	3.980	0.330	0.890
N. W. 10 of N. W. 40 of S. E. ¼ Sec. 13. Twp. 3 S. R. 28, W. of 6 P.M.	Grain 15 years, loam bottom land. Compare with 1798.	Soil 0–7	1801.1	0.121	0.090	1.750	1.210	0.120
		Subsurface 7–20	1801.2	0.063	0.086	3.780	0.590	0.800
		Subsoil a 20–40	1801.3	0.030	0.086	4.210	0.180	0.970
		Subsoil b 40–72	1801.4	0.020	0.084	3.060	0.090	0.590

Location	Description	Depth	No.					
—10 of N. E. 40 of S. W. ¼ Sec. 10. Twp. 12 S. R. 30, W. of 6 P.M.	Alfalfa 15 years, loam bottom land.	Soil 0-7	1802.1	0.133	0.098	2.080	1.440	0.240
		Subsurface 7-20	1802.2	0.067	0.095	2.150	0.570	0.290
		Subsoil a 20-40	1802.3	0.045	0.090	2.730	0.300	0.700
		Subsoil b 40-72	1802.4	0.039	0.078	4.810	0.280	1.170
—10 of the N. E. 40 of S. W. ¼ Sec. 10. Twp. 12 S. R. 30 W. of 6 P.M.	Native meadow loam bottom land. Compare with 1802.	Soil 0-7	1803.1	0.116	0.080	2.130	1.270	0.290
		Subsurface 7-20	1803.2	0.050	0.090	2.450	0.540	0.430
		Subsoil a 20-40	1803.3	0.043	0.088	2.730	0.410	0.560
		Subsoil b 40-72	1803.4	0.033	0.085	3.830	0.270	0.830
S. W. 10 of the S. W. 40 of N. W. ¼ Sec. Twp. 11 S. R. 28 W. of 6 P.M.	Farmed 30 years, mostly wheat, Colby silt loam. Compare with 1805.	Soil 0-7	1804.1	0.118	0.099	1.050	1.310	0.160
		Subsurface 7-20	1804.2	0.075	0.079	1.030	0.810	
S. E. 10 of the S. E. 40 of N. E. ¼ Sec. 7. Twp. 11 S. R. 28, W. of 6 P.M	Native Buffalo grass, Colby silt loam.	Soil 0-7	1805.1	0.170	0.079	1.200	2.060	
		Subsurface 7-20	1805.2	0.080	0.084	1.180	0.600	
S. E. 10 of the N. W. 40 of N. W. ¼ Sec. 18, Twp. 12 S. R. 27, W. of 6 P.M.	Alfalfa 20 years, then cane 3 years, loam bottom land.	Soil 0-7	1800.1	0.184	0.093	3.180	1.900	0.610
		Subsurface 7-20	1800.2	0.079	0.084	4.210	0.920	0.870
Sheridan County								
S. E. 10 of the S. E. 40 of the N. W. ¼ Sec. 28, Twp. 10 S. R. 28 W. of 6 P.M.	Alfalfa 20 years, loam bottom land.	Soil 0-7	1806.1	0.187	0.093	1.350	1.830	0.030
		Subsurface 7-20	1806.2	0.107	0.090	1.450	1.220	0.030
		Subsoil a 20-40	1806.3	0.057	0.082	2.150	0.380	1.230
		Subsoil b 40-80	1806.4	0.043	0.082	4.880	0.360	
S. W. 10 of the S. W. 40 of N. W. ¼ Sec. 28. Twp. 10 S. R. 28 W. of 6 P.M.	Native meadow, loam bottom land. Compare with 1806.	Soil 0-7	1807.1	0.182	0.064	1.200	2.270	0.310
		Subsurface 7-20	1807.2	0.115	0.087	1.200	1.200	
		Subsoil a 20-40	1807.3	0.064	0.097	2.300	0.700	0.900
		Subsoil b 40-72	1807.4	0.033	0.087	3.660	0.320	

TABLE 1—*Continued*

LOCATION, COUNTY AND LAND SURVEY	DESCRIPTION, TREATMENT, CHARACTER AND TYPE OF SOIL	STRATUM SAMPLED		LABORATORY NUMBER	PLANT-FOOD ELEMENTS				
			inches		Nitrogen	Phosphorus	Calcium	Organic carbon	Inorganic carbon
					per cent	*per cent*	*per cent*	*per cent*	*per cent*
Sheridan County—Continued									
N. W. 10 of the N. W. 40 of N. W. ¼ Sec. 30. Twp. 10 S.R.28, W. of 6 P.M.	Cultivated 20 years, creek bottom land. Compare with 1806.	Soil	0–7	1808.1	0.118	0.082	1.330	1.140	0.030
		Subsurface	7–20	1808.2	0.058	0.069	2.400	0.460	0.360
		Subsoil a	20–40	1808.3	0.034	0.085	3.530	0.160	0.720
		Subsoil b	40–72	1808.4	0.022	0.079	3.180	0.130	0.680
N. E. ¼ Sec. 6. Twp. 9 S. R. 28, W. of 6 P.M.	Alfalfa 20 years, Colby silt loam.	Soil	0–7	1809.1	0.153	0.084	1.680	1.630	0.110
		Subsurface	7–20	1809.2	0.066	0.084	4.060	0.660	1.260
		Subsoil a	20–40	1809.3	0.040	0.077	3.880	0.340	0.890
		Subsoil b	40–72	1809.4	0.026	0.082	3.430	0.160	0.720
N. E. ¼ Sec. 6. Twp. 9 S. R. 28 W. of 6 P.M.	Native meadow, Colby silt loam. Compare with 1809.	Soil	0.7	1810.1	0.157	0.098	1.200	1.820	0.540
		Subsurface	7–20	1810.2	0.072	0.084	3.180	0.620	0.610
		Subsoil a	20–40	1810.3	0.038	0.086	3.180	0.170	1.250
		Subsoil b	40–72	1810.4	0.035	0.076	5.050	0.080	
Wallace County									
Sec. 35 Twp. 13 S. R. 39, W. of 6 P.M.	Alfalfa 25 years, bottom land.	Soil	0–7	1811.1	0.182	0.099	2.470	1.760	0.280
		Subsurface	7–20	1811.2	0.039	0.063	3.970	0.660	0.400
		Subsoil	20–40	1811.3	0.101	0.073	2.800	0.390	0.840
Sec. 35. Twp. 13 S. R. 39 W of 6 P.M.	Native pasture, loam bottom land. Compare with 1811.	Soil	0–7	1812.1	0.151	0.080	2.750	1.890	0.400
		Subsurface	7–20	1812.2	0.088	0.070	3.000	1.110	0.210
		Subsoil	20–40	1812.3	0.052	0.055	3.130	0.470	0.600

Trego County

Location	Description	Sample	Depth	No.					
S. W. 10 of the S. W. 40 of S. W. ¼ Sec. 20. Twp. 12 S. R. 23 W. of 6 P.M.	Alfalfa over 20 years, creek bottom silt loam.	Soil	0–7	1794.1	0.131	0.072	1.180	1.060	0.053
		Subsurface	7–20	1794.2	0.052	0.095	2.430	0.660	0.340
		Subsoil a	20–40	1794.3	0.019	0.085	2.560	0.210	0.470
		Subsoil b	40–72	1794.4	0.017	0.084	2.200	0.290	0.230
N. E. 10 of the S. W. 40 of S. W. ¼ Sec. 20. Twp. 12 S. R. 23 W. of 6 P.M.	Wheat prevailing crop, creek bottom land near higher ground, loam or silt loam. Compare with 1794.	Soil	0–7	1795.1	0.160	0.073	1.050	1.840	
		Subsurface	7–20	1795.2	0.076	0.073	1.200	0.800	
		Subsoil a	20–40	1795.3	0.040	0.088	1.100	0.450	
		Subsoil b	40–72	1795.4	0.022	0.099	1.900	0.430	

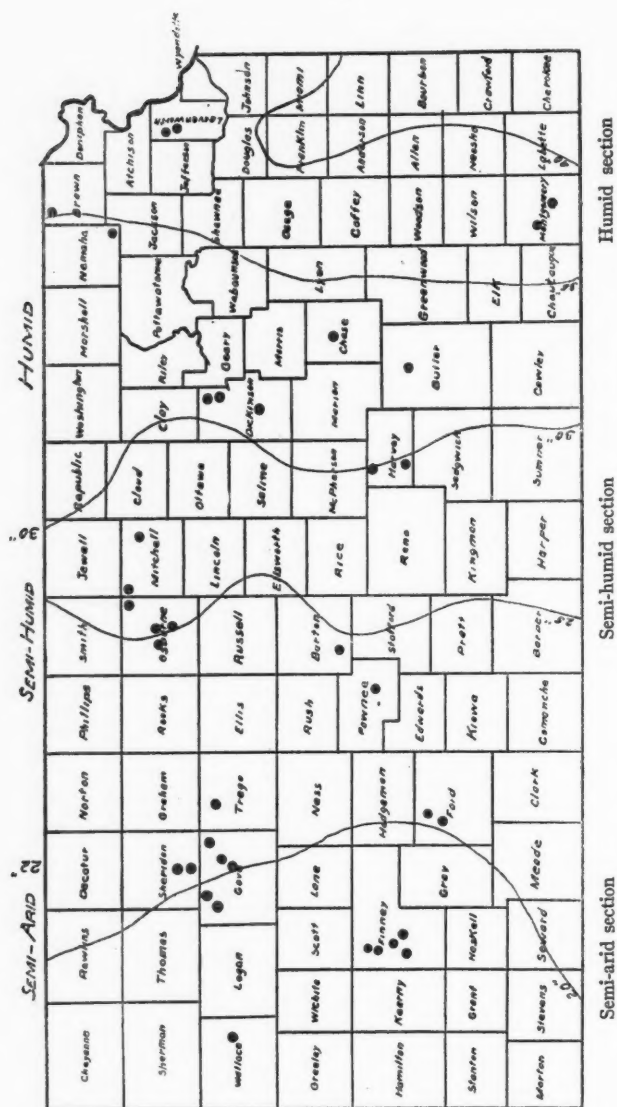C. O. SWANSON AND W. L. LATSHAW

FIG. 1. OUTLINE MAP OF KANSAS, SHOWING THE APPROXIMATE LOCATION WHERE THE SAMPLES WERE TAKEN

problem.   A ton of average alfalfa hay contains about 5 pounds of phosphorus. If a soil analyzes 0.05 per cent of phosphorus, the amount to the depth of 40 inches is 6,000 pounds per acre.   Calculating an average yield of 4 tons per year, the amount of phosphorus removed from the soil in 20 years is 400 pounds or a little over 6 per cent of this total.   This is quite likely no greater than the difference in the composition of adjoining fields when they were in virgin sod.

The foregoing review shows that when land is in a wild or virgin state, the supply of nitrogen is kept constant or increases; but as soon as the land is cultivated there is a tendency for the nitrogen content to decrease, and that not all of this decrease can be attributed to the removal of nitrogen by the crop.   It is also shown that legumes tend to increase the nitrogen content of the soil.

EXPERIMENTAL

The general plan of the experiment reported in this paper was to sample old alfalfa fields, old cultivated fields near by, and virgin sod wherever they could be found adjoining or in close proximity separated by a fence or road. The samples were generally taken in four different strata, namely 0 to 7 inches, 7 to 20 inches, 20 to 40 inches and 40 to 80 inches in depth.   These are called surface, subsurface and first and second subsoil, respectively.   For the upper three strata a soil augur was generally used.   For the lowest it was found best to use a soil tube, particularly in Western Kansas.   Borings were made in a number of places in each field.   In Western Kansas most of the fields were on bottom land.

The soil samples were put in bags and shipped to the laboratory.   When thoroughly air-dry, the whole sample was put in a ball mill and given a preliminary grinding.   This served to mix the sample thoroughly.   A small subsample was then ground in an ore sample grinder to pass a 100-mesh sieve.

The samples were analyzed for nitrogen, organic carbon, inorganic carbon, phosphorus and calcium.   The results of the analyses are given in table 1. The location of the field as given in the first column is by county and by legal description.   The location is also indicated in figure 1.   In a few cases one field was compared with another across the road and in another county.   In such cases the location does not exactly correspond to the county under which it is classed.

There is given in the table a brief description of the soil and its treatment as far as known.   For purposes of comparative study, the samples have been divided into three classes according to the location in the state and the amount of rainfall.   The samples taken from locations where rainfall is 30 inches or more are classed as from the humid section; those taken where the annual rainfall is between 22 and 30 inches as from the sub-humid, and those where the rainfall is less than 22, as from the semi-arid portions of the state.

TABLE 2

Effect of cropping on the nitrogen content of the surface 7 inches of soil

COUNTY	NITROGEN: POUNDS PER ACRE			DIFFERENCE					
	Native	Alfalfa	Cropped	Alfalfa vs. native		Cropped vs. native		Alfalfa vs. cropped	
				lbs.	*per cent*	*lbs.*	*per cent*	*lbs.*	*per cent*
Humid section									
Leavenworth...........		3260	3480					−220	6.75
Leavenworth...........	5920	4440		−1480	25.00				
Brown.................	4560	4220	3200	+340	7.46	1360	29.83	+1020	24.17
Nemaha...............	3620	3400	2040	−220	6.07	−1580	43.64	+1360	40.00
Montgomery..........	3720	2620	2200	−1100	29.56	1520	40.70	+400	16.04
Montgomery..........		3360	2700					+660	19.64
Butler................	3920	3220	2780	−700	17.85	−1140	29.10	+440	13.66
Chase.................	3840	4020	2660	+180	4.68	−1180	30.73	+1360	33.83
Harvey................	3780	3220	2800	−560	14.81	−980	25.92	+420	13.03
Harvey................	4440	4000	2480	−440	9.90	−1960	44.14	+1520	38.00
Dickinson.............	4080	3360	2800	−720	17.64	−1280	31.37	+560	16.66
Dickinson.............	4080	3580	3260	−500	12.25	−820	20.09	+320	8.94
Dickinson.............	4180	4020	3100	−160	3.81	−1080	25.83	+920	22.88
Average.............	4195	3592	2793	−549	13.55	−1290	32.13	+827	22.31
Sub-humid section									
Mitchell..............		4080	3600					+480	11.76
Mitchell..............	4760	5380		+620	13.02				
Mitchell..............	5800		3720			−2080	35.86		
Mitchell..............	3600	3200	2580	−400	11.11	−1020	28.33	+620	19.37
Mitchell..............	3060		2300			−760	24.83		
Osborne..............	5000	3680	2680	−1320	26.40	−2320	46.40	+1000	27.19
Osborne..............	4640		4220			−420	9.05		
Osborne..............	4400	3920	2860	−480	10.90	−1540	35.00	+1060	27.04
Barton...............	2120	3180	2740	+1060	50.00	+620	29.44	+440	13.83
Pawnee...............	4280	4420	4020	+140	3.27	−260	6.07	+400	9.05
Average.............	4184	3980	3191	−204	4.87	−993	23.75	+789	18.04
Semi-arid section									
Ford.................	3420	4200	2720	+780	22.80	−700	20.49	+1480	35.23
Ford.................	3040	3120	2360	+80	2.63	−680	22.36	+760	24.35
Finney...............	2740	3360		+620	22.62				
Finney...............	2700	4000	2680	+1300	48.14	−20	0.74	+1320	33.00
Finney...............		3560	1580					+1980	55.62
Finney...............	1980	3840	1940	+1860	93.93	−40	2.02	+1900	49.47
Trego................		2620	3200					−580	22.13
Gove.................	3080		2560			−520	16.88		
Gove.................	3760	4200	2420	+440	11.70	−1340	35.63	+1780	42.38
Gove.................	2320	2600		+340	14.67				
Gove.................	3400		2360			−1040	30.58		
Sheridan.............	3640	3740	2360	+100	2.74	−1280	34.06	+1380	36.89
Sheridan.............	3140	3060		−80	2.55				
Wallace..............	3020	3640		+620	20.54				
Average.............	3020	3495	2418	+606	24.23	−702	20.48	+1077	37.38

THE EFFECT OF CROPPING ON THE NITROGEN CONTENT OF THE SOIL

The number of pounds of nitrogen per acre in 7 inches of the surface soil has been presented in table 2.   The differences for virgin soils and for soils cropped in different ways are also given.   Soil in native sod is compared with soil cropped to alfalfa, and also with soil which has grown crops other than legumes.   A comparison is also made between soil cropped to alfalfa and soils that have grown crops other than legumes.   In the first case the native sod is used as the basis of comparison and the second case the soil that had been cropped to alfalfa.   The comparison is made both in pounds per acre and on a percentage basis.   In calculating the number of pounds per acre, the following weights of soil are assumed:

pounds

Surface, 0–7 inches.. 2,000,000
Subsurface, 7–20 inches....................................... 4,000,000
First subsoil, 20–40 inches.................................... 6,000,000
Second subsoil, 40–80 inches................................. 12,000,000

The results are summarized in table 3.

TABLE 3

Effect of cropping on the nitrogen content of surface soil: Summary

	POUNDS OF NITROGEN PER ACRE		
	Native	Alfalfa	Cropped
Humid...................................	4195	3592	2793
Sub-humid..............................	4184	3980	3191
Semi-arid...............................	3020	3495	2418

In the humid section the cropped soils contained on the average 1402 pounds less nitrogen per acre than the native soils.   This means a loss of nearly one-third of the original amount of nitrogen.   The soils which had been in alfalfa contained 799 pounds more nitrogen than soils which had grown other crops than legumes, but 603 pounds less than the native soils.   This is a loss of 14.3 per cent as compared with the native soils but an increase of 21.6 per cent as compared with the cropped soil.

In the sub-humid section the cropped soils contained 993 pounds less nitrogen than the soils in native sod.   This is a loss of nearly one-fourth.   The soils in alfalfa contained 789 pounds more nitrogen than the cropped soils, but 204 pounds less than the soils in native sod, a loss in this case of only 5 per cent as compared with the native sod and a gain of 20 per cent as compared with the cropped soil.

In the semi-arid section the cropped soils contained 602 pounds less nitrogen than the soils in native sod, or a loss of one-fifth of the original nitrogen. The alfalfa soils contained 475 pounds of nitrogen more than the native soils, and 1077 pounds more than the cropped soils.

All the fields in alfalfa but one have more nitrogen than those in native sod. In every cropped field but one, the nitrogen content was less than in the native sod. In other words, the fields in alfalfa have over 30 per cent more nitrogen than the cropped soils, and 15.7 per cent more than the soils in native sod. This represents an unmistakable gain of nitrogen through the growing of alfalfa. It should be borne in mind that the average age of the alfalfa fields in the sub-humid and semi-arid section was much greater than that of the fields in the humid section.

It is probable that the decrease in nitrogen of the fields in alfalfa in the humid and sub-humid sections took place before the alfalfa was seeded. The increase in nitrogen, if any, since the alfalfa was seeded has not been sufficient to restore the original amount. For reasons to be presented later, it is probable that in some fields at least, the growth of alfalfa has simply prevented a further decrease.

Perhaps more accurate conclusions can be drawn from the data presented in table 4 in which only those fields are included which were close enough together to permit direct comparisons. The figures in the first three columns are the same as those in table 2. In the next two columns are given the number of years of continuous alfalfa or grain production in the respective fields. By subtracting the number of pounds of nitrogen in the continuously cropped field from that in native sod, the loss of nitrogen by cropping is obtained. These figures are given in the sixth column. The average yearly loss obtained by dividing the total by the number of years in cultivation is given in the seventh column.

The average yearly loss multiplied by the number of years the land was in grain crops gives the total loss sustained before seeding to alfalfa. The figures so obtained are given in the eighth column. Subtracting this from the amount present in the native sod gives the amount presumably present in the soil when the alfalfa was seeded. These figures are given in the ninth column. By comparing this amount with that present when the sample was taken the gain or loss through the continuous growing of alfalfa can be calculated. The results of this calculation are given in the last column of table 4.

It will be seen that in both the humid and the sub-humid sections, the gains are practically balanced by the losses. The growing of alfalfa has simply prevented further losses or has secured enough from the air to take the place of that removed by the crop. In the semi-arid section there is an unmistakable gain. This corroborates the statements made on the basis of the figures presented in table 2.

If continuous growing of alfalfa simply maintains a balance in the nitrogen content of the soil, it seems that the amount of nitrogen in the hay crop is about equal to that obtained from the air, while that in the roots and stubble is about equal to that obtained from the soil.

Another factor however, must be considered, viz; the loss of leaves in curing and stacking.   The loss is probably greater in the semi-arid section than in the more humid sections.   The intense sunshine causes the leaves to fall very easily if the period of drying is prolonged even a few hours.   It has been calculated that from 7 to 25 per cent of the leaves are lost in curing and stacking, and from 3 to 14 per cent of the entire crop (9).

TABLE 4

Gain or loss of nitrogen as a result of cropping to alfalfa

COUNTY	POUNDS OF NITROGEN PER ACRE			YEARS IN ALFALFA	YEARS IN A GRAIN CROP	LOSS OF NITROGEN			NITRO-GEN PER ACRE WHEN SEEDED	GAIN OR LOSS WHILE IN ALFALFA
	Alfalfa	Native	Cropped			Total loss by cropping to grains	Average yearly loss	Loss before seeding to alfalfa		
Humid section										
						lbs.	lbs.	lbs.	lbs.	lbs.
Brown..........	4220	4560	3200	28	45	1380	31	527	4050	+170
Nemaha.........	3420	3620	2040	21	45	1580	35	840	2760	+649
Montgomery.....	2620	3720	2200	12	35	1520	43	989	2730	−110
Butler..........	3220	3920	2780	12	32	140	4	80	3840	+620
Chase..........	4020	3840	2660	25	40	1180	29	435	3405	+615
Harvey..........	3220	3780	2800	11	25	980	39	546	3234	−14
Harvey..........	4000	4440	2480	14	44	1960	44	1320	3120	+880
Dickinson.......	3360	4080	2800	20	35	1280	37	555	3530	−170
Dickinson.......	3580	4080	3260	20	40	820	20	400	3680	−100
Dickinson.......	4020	4180	3100	25	35	1080	31	310	3870	+150
Sub-humid section										
Mitchell.........	3200	3600	2580	23	30	1020	34	238	3370	−170
Osborne.........	3680	5000	2680	20	40	2320	58	1160	3840	−160
Osborne.........	3920	4400	2860	33	35	1540	44	88	4310	−390
Pawnee.........	4420	4280	4020	28	20	260	13	0	4280	+140
Semi-arid section										
Ford...........	4200	3420	2720	30	30	700	23	0	3420	+780
Ford...........	3120	3040	2360	10	30	680	22	220	2580	+540
Finney.........	4000	2700	2680	27	20	20	0	0	2700	+1300
Finney.........	3840	1980	1940	30	30	40	0	0	1980	+1860
Gove...........	4200	3760	2420	15	15	1340	89	0	3760	+440
Sheridan........	3740	3640	2360	20	20	1280	64	0	3640	+100

We may assume that on the average, 20 per cent of the leaves, or about 10 per cent of the crop, is lost.   When bad weather prevails during harvesting, as much as half the crop may be lost.   This no doubt is a factor in increasing the nitrogen content of the soil.   Assuming an annual yield of hay of 5000 pounds per acre, half of which is leaves, the nitrogen added to the soil in

TABLE 5

Effect of cropping on the organic carbon in the surface 7 inches of soil

COUNTY	POUNDS OF ORGANIC CARBON PER ACRE			DIFFERENCE					
	Native	Alfalfa	Cropped	Alfalfa vs. Native (lbs.)	(per cent)	Cropped vs. Native (lbs.)	(per cent)	Alfalfa vs. Cropped (lbs.)	(per cent)
Humid section									
Leavenworth		32,200	37,400					−5,200	16.14
Leavenworth	75,200	50,000		−25,200	33.51				
Brown	57,200	45,600	38,800	−11,600	20.25	−18,400	32.16	+6,800	14.91
Nemaha	39,400	33,800	22,600	−5,600	14.21	−16,800	42.64	+11,200	30.18
Montgomery	51,800	41,400	34,600	−10,400	20.07	−17,200	33.20	+6,800	16.42
Montgomery		46,400	41,000					+5,400	11.63
Butler	47,000	34,200	30,800	−12,800	27.23	−16,200	34.46	+3,400	9.94
Chase	47,600	44,600	36,000	−3,000	6.30	−11,600	24.36	+8,600	19.28
Harvey	45,600	38,200	22,400	−7,400	16.22	−23,200	50.87	+15,800	41.36
Harvey	53,200	46,200	24,600	−7,000	13.16	−28,600	53.75	+21,600	46.75
Dickinson	49,200	36,400	36,400	−12,800	26.01	−12,800	26.01	0	0
Dickinson	52,600	40,000	40,120	−12,600	23.95	−12,480	23.72	−120	00.30
Dickinson	60,600	50,200	41,200	−10,400	17.16	−19,400	32.01	+9,000	17.92
Average	52,673	41,477	33,810	−11,196	21.26	−18,863	35.82	+7,667	18.48
Sub-humid section									
Mitchell	62,800	64,600		+1,800	3.00				
Mitchell		48,400	43,600					+4,800	9.91
Mitchell	57,900		41,800			−16,100	27.80		
Mitchell	37,400	25,200	28,400	−12,200	32.62	−9,000	24.06	−3,200	12.69
Mitchell	35,600		26,800			−8,800	24.71		
Osborne	62,200	44,400	35,400	−17,800	28.61	−26,800	43.08	+9,000	20.27
Osborne	64,400	46,000	33,200	−18,400	25.57	−31,200	48.45	+12,800	27.82
Osborne	74,200		53,000			−21,200	28.57		
Barton	25,600	38,200	33,600	+12,600	49.21	+8,000	31.25	+4,600	12.09
Pawnee	50,600	51,200	42,200	+600	1.18	−8,400	16.60	+9,000	17.57
Average	52,289	45,429	37,556	−6,860	13.12	−14,733	28.19	+7,873	17.33

Semi-arid section

Ford.........	72,000	41,600	36,400	−30,400	42.22	−35,600	49.44	+5,200	12.50
Ford.........	34,800	33,200	29,600	−1,600	4.59	−5,200	14.94	+3,600	10.84
Finney.......	33,600	38,600	35,200	+5,000	14.88	+1,600	4.76	+3,400	8.80
Finney.......	38,800	32,200		−6,600	17.01				
Finney.......	17,800	40,800	19,600	+23,000	29.21	+1,800	10.11	+21,200	51.96
Finney.......		34,400	20,800					+13,600	39.54
Trego........	43,200	21,200	36,800	+1,400	3.24			−15,600	73.58
Gove.........	25,400	44,600	24,200	+3,400	13.38	−19,000	43.98	+20,400	45.74
Gove.........	36,800	28,800							
Gove.........	41,200		27,000			−9,800	26.63		
Gove.........	45,400		26,200			−15,000	36.40		
Sheridan.....	36,400	36,600	22,800	−8,800	19.38			+13,800	37.70
Sheridan.....	37,800	32,600		−3,800	10.43	−22,600	49.78		
Wallace......		35,200		−2,600	6.87				
Average......	38,600	34,983	27,860	−3,846	9.96	−10,740	27.83	+8,200	+23.50

this way would amount to 17.5 pounds annually or a total of 350 pounds in 20 years. There may be two reasons for no apparent gain in the humid and sub-humid sections: (1) The leaves remain on the surface of the soil and the nature of the decay is such that a portion of the nitrogen is lost. (2) Alfalfa uses the nitrogen liberated by decay and nitrification of organic matter. When the nitrogen is abundant more nitrogen is used. In this way the addition of nitrogen through the loss of leaves may create such a condition that less is taken from the air.

The fact must not be lost sight of that alfalfa takes large amounts of nitrogen from the air which is not accounted for in this investigation, because no data on the amount removed in the crops are available. For every ton of hay harvested, it appears that 50 pounds of nitrogen has been taken from the air. With the best methods of farming the greater part of this can be returned to the soil.

Another effect of growing alfalfa is an improved physical condition of the soil, as a result of the large, deeply penetrating roots. Alfalfa roots are large and contain a large amount of organic matter; they decay easily and rapidly making available an abundance of the mineral elements, phosphorus, and potassium contained in the alfalfa roots. The process of decay also liberates more of these elements from the insoluble compounds found in the soil.

Finally it should be remembered that the fields studied were comparatively well stocked with nitrogen when alfalfa was seeded. If the investigation had been made on fields which had lost more nitrogen before the alfalfa was seeded, the results probably would be different.

THE EFFECT OF CROPPING ON THE ORGANIC CARBON CONTENT OF THE SOIL

The organic carbon content of surface soil of fields in native sod, alfalfa and those cropped to grain is given in table 5. The differences are also given in pounds and percentage, the comparisons being made as in table 2. The results are summarized in table 6.

In the humid section the fields cropped to grain contain on the average 18,863 pounds less of organic carbon than those in native sod, an average loss of nearly 36 per cent. The fields in alfalfa contain an average of 7667 pounds more than those in grain crops, but 11,196 pounds less than those in native sod. This is a loss of 21.26 per cent as compared with the native sod and a gain of 18.48 per cent as compared with the cropped fields. All the soils in native sod have more organic carbon than the fields in alfalfa or those cropped to grains. All but two of the fields in alfalfa have more organic carbon than the fields cropped to grains.

In the sub-humid section the fields cropped to grains contain an average of 14,733 pounds less of organic carbon than the native sod. This is a loss of nearly 28 per cent. The fields in alfalfa contained an average of 7873 pounds of organic carbon more than those in grains, but 6860 pounds less

than the fields in native sod.   This is a loss of a little over 13 per cent as compared with the native sod and a gain of over 18 per cent as compared with the cropped land.

In the semi-arid section the fields cropped to grain contained 10,740 pounds less organic carbon than those in native sod.   This is a loss of nearly 30 per cent.   Those in alfalfa contained on the average 7123 pounds more organic carbon than those cropped to grains, but 3817 pounds less than those in native sod, a loss of about 10 per cent as compared with the native sod, and a gain of over 25 per cent as compared with the fields cropped to grains.   All but four of the fields in native sod contained more organic carbon than those cropped to alfalfa or grain.

These results show that the growing of alfalfa has not fully restored the organic carbon.   There is no doubt as to the possibility of increasing the organic carbon content of the soil by growing alfalfa, but in the majority of cases studied, such cropping has resulted in a further decrease.

We must recognize the possibility of error in the determinations, since we do not know the exact carbon content of these fields, at the time the alfalfa

TABLE 6

Effect of cropping on the organic carbonic content of the surface soil: Summary

	POUNDS PER ACRE		
	Native	Alfalfa	Cropped
Humid......................................	52,673	41,477	33,810
Sub-humid.................................	50,638	45,429	37,536
Semi-arid..................................	38,433	34,983	26,720

was seeded.   The approximate amounts can be calculated however, by the same method employed in studying the loss of nitrogen.   Data secured by this method are presented in table 7.

The data corroborate those presented in table 5 and the statements made in relation to them.   Unlike the effect on the nitrogen there has not been an increase in the carbon content of these soils as a result of cropping to alfalfa. This is true for all the three sections.

THE EFFECT OF CROPPING ON THE NITROGEN AND ORGANIC CARBON CONTENT
OF THE SUBSOIL

An attempt has been made to compare the nitrogen and organic carbon content of the different strata.   The results are presented in tables 8 and 9. In interpreting these results it should be remembered that the experimental errors of determination are rather large.   There are two reasons for this. Most of these samples are from bottom land.   While the fields compared appeared to be very uniform, the subsoils were often found to differ considerably.   Also the weight of the subsoil from 20 to 40 inches deep was assumed

TABLE 7

Gain or loss of organic carbon as a result of cropping to alfalfa

COUNTY	POUNDS OF ORGANIC CARBON PER ACRE			YEARS IN ALFALFA	YEARS IN GRAIN CROP	LOSS OF ORGANIC CARBON			POUNDS OF ORGANIC CARBON PER ACRE WHEN SEEDED	GAIN OR LOSS WHILE IN ALFALFA
	Alfalfa	Native	Cropped			Total loss by cropping to grain	Average yearly loss	Loss before seeding to alfalfa		
						lbs.	lbs.	lbs.		lbs.
Humid section										
Brown.........	45,600	57,200	38,800	28	45	18,400	409	6,953	50,247	−4,647
Nemaha........	33,800	39,400	22,600	21	45	16,800	373	8,952	30,448	+3,352
Montgomery....	41,400	51,800	34,600	12	35	17,200	491	11,293	40,507	+893
Butler.........	34,200	47,000	30,800	12	32	16,200	506	10,120	36,880	−2,680
Chase.........	44,600	47,600	36,000	25	40	11,600	290	4,350	43,250	+1,350
Harvey........	38,200	45,600	22,400	11	25	23,200	928	12,992	32,608	+5,592
Harvey........	46,200	53,200	24,600	14	44	28,600	650	19,500	33,700	+12,500
Dickinson.....	36,400	49,200	36,400	20	35	12,800	365	5,475	43,725	−7,325
Dickinson.....	40,000	52,600	40,120	20	40	12,480	312	6,240	46,360	−6,360
Dickinson.....	50,200	60,600	41,200	25	35	19,400	554	5,540	55,060	−4,860
Sub-humid section										
Mitchell.......	25,200	37,400	28,400	23	30	9,000	300	2,100	35,300	−10,100
Osborne.......	46,000	64,400	33,200	20	40	31,200	780	15,600	48,800	−1,800
Osborne.......	44,400	62,200	35,400	33	35	26,800	765	1,530	60,670	−16,270
Pawnee........	51,200	50,600	42,200	28	20	8,400	420	0	50,600	+600
Semi-arid section										
Ford..........	41,600	72,000	36,400	30	30	35,600	1,186	0	72,000	−30,400
Ford..........	33,200	34,800	29,600	10	30	5,200	173	3,460	31,340	+1,860
Finney........	38,600	33,600	35,200	27	20	−1,600*	−80	0	33,600	+5,000
Finney........	40,800	17,800	19,600	30	30	−1,800*	−60	0	17,800	+23,000
Gove..........	44,600	43,200	24,200	15	15	19,000	1,260	0	43,200	+1,400
Sheridan......	36,600	45,400	22,800	20	20	22,600	1,130	0	45,400	−8,800

* Gain.

to be 6,000,000 pounds per acre, and the subsoil from 40 to 80 inches 12,000,000 pounds per acre. When these sums are multiplied by the significant errors in the determinations, the differences between duplicate determination is often greater than the differences due to the cropping.

It will be seen that the method of cropping has not influenced materially the nitrogen content of the subsoil below a depth of 20 inches, except possibly

TABLE 8

Average nitrogen content of the soil of different strata

SECTION	KIND OF SOIL	0-7 INCHES	7-20 INCHES	20-40 INCHES	40-80 INCHES
		per cent	*per cent*	*per cent*	*per cent*
Humid.................	Native	0.200	0.121	0.069	0.045
	Alfalfa	0.175	0.111	0.062	0.043
	Cropped	0.136	0.105	0.068	0.046
Sub-humid.............	Native	0.209	0.101	0.059	0.032
	Alfalfa	0.200	0.092	0.061	0.033
	Cropped	0.159	0.088	0.051	0.036
Semi-arid...............	Native	0.151	0.079	0.048	0.037
	Alfalfa	0.173	0.077	0.051	0.035
	Cropped	0.121	0.073	0.042	0.025

TABLE 9

Average carbon content of the soil of different strata

SECTION	KIND OF SOIL	0-7 INCHES	7-20 INCHES	20-40 INCHES	40-80 INCHES
		per cent	*per cent*	*per cent*	*per cent*
Humid.................	Native	2.52	1.39	0.77	0.44
	Alfalfa	2.09	1.27	0.72	0.48
	Cropped	1.67	1.23	0.81	0.43
Sub-humid.............	Native	2.72	1.16	0.67	0.31
	Alfalfa	2.27	1.14	0.90	0.63
	Cropped	1.88	1.11	0.54	0.69
Semi-arid...............	Native	1.93	0.71	0.41	0.34
	Alfalfa	1.63	0.74	0.46	0.37
	Cropped	1.39	0.70	0.55	0.29

in the semi-arid section. In the subsurface (7 to 20 inches), the nitrogen content of the fields in native sod is slightly higher than the others, the difference being greatest when the comparison is made with the fields cropped to grain. It is sometimes thought that plants secure nitrogen from the subsoil and deposit it in the surface soil. The facts here presented do not support this theory.

TABLE 10

Effect of cropping on the phosphorus content of the surface 7 inches of soil

COUNTY AND SECTION	POUNDS OF PHOSPHORUS PER ACRE			DIFFERENCES					
	Native	Alfalfa	Cropped	Alfalfa vs. native		Cropped vs. native		Alfalfa vs. cropped	
				lbs.	per cent	lbs.	per cent	lbs.	per cent
Humid									
Leavenworth...........	1220	1040		−180	14.75				
Leavenworth..........		860	960					−100	9.61
Brown...............	1220	1260	960	+40	3.27	−260	21.31	+300	23.80
Nemaha.............	760	780	800	+20	2.63	+40	5.26	−20	2.56
Montgomery..........	920	720	680	−200	21.73	−240	26.08	+40	5.55
Montgomery..........		860	760					+100	11.62
Butler..............	700	760	540	+60	8.57	−160	22.85	+220	28.94
Chase...............	1000	780	840	−220	22.00	−160	16.00	−60	7.69
Harvey..............	1120	820	1060	−300	26.78	−60	5.35	−240	29.26
Harvey..............	900	860	720	−40	4.44	−180	20.00	+140	16.27
Dickinson............	960	960	1140	0	0	+180	18.75	−180	18.75
Dickinson............	1220	880	960	−340	27.86	−260	21.31	−80	9.09
Dickinson............	1740	1820	900	+80	4.59	−840	48.27	+920	50.54
Average............	1069	954	860	−115	10.76	−209	19.55	+94	9.85
Sub-humid									
Mitchell..............	1260	1380		+120	9.52				
Mitchell..............	1360	1580	1300	+220	16.17	−60	4.41	+280	17.72
Mitchell..............	1100		1140			+40	3.63		
Mitchell..............	2100		1920	−720	34.29	−180	8.57	−540	39.13
Mitchell..............		1500	1440	+240	19.05	+180	14.28	+60	4.00
Osborne.............	2000	1400	1800	−600	30.00	−200	10.00	−400	28.57
Osborne.............	1360	1200	1340	−160	11.76	−20	1.47	−140	11.66
Osborne.............	2120		2060			−60	2.83		
Barton..............	1040	1080	940	+40	3.84	−100	9.61	+140	12.96
Pawnee.............	1180	1060	1860	−120	10.17	+680	57.71		75.47
Average............	1502	1314	1533	−123	16.85	+31	2.06	−219	16.67
Semi-arid									
Ford.................	1580	1640	1500	+60	3.79	−80	5.06	+140	8.53
Ford.................	860	1640	1260	+780	90.61	+400	46.51	+380	23.17
Finney..............	1540	1520		−20	1.29				
Finney..............	1640	1700	1400	+60	3.65	−240	14.63	+300	17.64
Finney..............	1360	1560	1240	+200	14.70	−120	8.82	+320	20.51
Finney..............		1280	1060					+220	17.18
Trego...............		1440	1460					−20	1.38
Gove................	1720	2000	1800	+280	16.27	+80	4.65	+200	10.00
Gove................	1600	1960		+360	22.50			−600	40.00
Gove................	1680	1500	2100	−180	10.71	+420	25.00		
Gove................	1580		1980			+400	25.31		
Sheridan............	1280	1860	1640	+580	45.31	+360	28.10	+220	11.82
Sheridan............	1960	1680		−280	14.28				
Wallace.............	1600	1980		+380	23.75				
Average............	1533	1674	1544	+141	9.19	+152	10.00	+130	8.48

The organic carbon content of the subsoil below 20 inches appears not to be materially affected by the method of cropping. In two cases the carbon content of the fields cropped to grain is the highest of any. This suggests that the differences are less than the error of determination. There appears to be a significant though slight difference in the subsurface (7 to 20 inches) in favor of the fields in native sod. Also, those in alfalfa appear to be slightly higher in carbon than those cropped to grain. As previously pointed out there are rather large differences in the carbon content of the surface soil (0 to 7 inches).

The fact that the principal loss of carbon is in the surface soil suggests that it is practically all due to the oxidation of organic matter, to soil blowing or to erosion. These factors also affect the nitrogen content.

THE EFFECT OF CROPPING ON THE PHOSPHORUS CONTENT OF THE SOIL

The phosphorus content of the soil is indicated in table 10. The data are arranged in the same way as for the nitrogen and for the organic carbon content presented above. In general, the differences are so small that no definite conclusions can be reached.

A ton of alfalfa hay contains about 5 pounds of phosphorus. At this rate 20 average crops would remove only about 500 pounds. If all of it came from the surface soil the removal of this amount no doubt would be noticeable, but a deep-rooted crop like alfalfa secures phosphorus from considerable depth. The smallest difference which can possibly be significant in a phosphorus determination is 0.005 per cent. This amounts to 600 pounds of phosphorus per acre to a depth of 40 inches assuming the weight of the soil to be 12,000,000 pounds. Accordingly, the amount of phosphorus removed by 20 average crops of alfalfa could not be determined with any degree of certainty. Also, there is no certainty that all fields had the same phosphorus content to begin with.

Considering the possibilities of error it is not probable that the differences in the phosphorus content of the fields cropped in different ways are significant. The rather high phosphorus content of the surface soil of the fields cropped to alfalfa in the semi-arid section is perhaps explained by the loss of leaves in curing.

The phosphorus content of the different strata is presented in table 11. Excepting only the cropped soils in the humid section, the surface averages higher in phosphorus than the subsoils. This accords with what would be expected. The phosphorus in the native vegetation becomes incorporated with the surface soil when the former decays or is burned off.

The fact that the cropped soils in the humid section do not contain more phosphorus than the lower strata may be taken to mean that so much of the phosphorus of the surface soil has been used that the average has been reduced to that found in the lower depths. In the sub-humid and semi-arid sections the soils have not been cultivated for so long a time, therefore this condition has apparently not yet been reached.

THE EFFECT OF CROPPING ON THE CALCIUM CONTENT OF THE SOIL

The principal object in analyzing the soils for calcium was to determine the calcium content of soils where alfalfa grows successfully. The amount of calcium in crops is small in comparison with the amount present in the soil, and with the amounts removed from the soil by leaching. A ton of alfalfa hay contains from 20 to 25 pounds of calcium. The amount in grain crops is much smaller. On the other hand, it is estimated that the equivalent of 500 pounds per acre of CaCO₃ is removed by leaching every year in a humid climate. The amount of calcium in these soils varies more than that of any other element.

As a rule the calcium content increases from the surface downward. This is especially true for soils with a high calcium content and for the sub-humid and semi-arid sections. By reference to table 1 it will be seen that most

TABLE 11

Phosphorus, average percentages in different strata

SECTION	KIND OF SOIL	0–7 INCHES	7–20 INCHES	20–40 INCHES	40–80 INCHES
		per cent	*per cent*	*per cent*	*per cent*
Humid section	Native	0.053	0.041	0.039	0.039
	Alfalfa	0.046	0.039	0.037	0.044
	Cropped	0.042	0.041	0.042	0.042
Sub-humid	Native	0.075	0.063	0.064	0.056
	Alfalfa	0.066	0.062	0.059	0.057
	Cropped	0.075	0.066	0.065	0.057
Semi-arid	Native	0.079	0.070	0.064	0.072
	Alfalfa	0.084	0.067	0.067	0.067
	Cropped	0.077	0.068	0.070	0.070

soils in the humid section contain from 0.5 to 1.0 per cent calcium in the surface soil. Of those devoted to alfalfa growing, few contained less than 0.5 per cent of calcium. In the sub-humid and semi-arid sections the percentage of calcium in practically all soils studied is 1 per cent and above. In none of the soils of these two sections can there be said to be a calcium deficiency. It is very probable that those soils which contain 0.5 per cent or less calcium are very near the border-line of calcium deficiency, and especially so when there is no material increase in calcium in the lower strata.

THE EFFECT OF CROPPING ON THE INORGANIC CARBON CONTENT OF THE SOIL

In the humid section only 6 out of 38 soils contained inorganic carbon in the surface or subsurface (table 1). In the subsoil, the occurrence of inorganic carbon was more frequent. This means that in this section calcium carbonate is absent from all but a very few soils and that the carbonate has disap-

peared from the surface and subsurface to a larger extent than from the sub-soil.   This shows that these soils are rapidly approaching a calcium deficiency. The calcium in forms other than the carbonate are relatively unavailable. In the sub-humid and semi-arid sections, only 11 soils out of 60 have no in-organic carbon in the surface soil, and of these 11, only 5 have no inorganic carbon in the subsoil.   This means that practically all soils in the sub-humid and semi-arid sections have not only an abundance of calcium but that a large amount of it is in the carbonate form which is the most available.

SUMMARY AND CONCLUSIONS

1. It is generally assumed that alfalfa helps maintain the fertility of the soil by securing nitrogen from the air and by preventing the oxidation of the humus and organic matter which takes place rapidly when cultivated crops are grown; no exact figures seem to have been secured, however.   It is very important that such data be available because when the alfalfa crop is re-moved it is quite possible that the field is left no richer in nitrogen than if no alfalfa had been grown, and because alfalfa removes a relatively large amount of other plant-food elements.

2. Kansas produces more alfalfa than any other state, and has some of the oldest alfalfa fields in the country, some of which have been continuously in alfalfa for 30 years or more.   This offers unusual opportunities: or a study of this kind.

3. The general plan of the experiment was to sample these old alfalfa fields and other fields nearby which were of the same type of soil but had been con-tinuously in cultivation or in native sod.   Preference was given to those locations where all these three fields were close enough together for direct comparison.   The soil was generally sampled in four depths: 0 to 7 inches, 7 to 20 inches, 20 to 40 inches, and 40 to 80 inches.   The samples were ana-lyzed for nitrogen, organic carbon, inorganic carbon, phosphorus and calcium.

4. For purposes of comparisons, the state was divided into three sections; humid, sub-humid and semi-arid.   The basis of division was the average annual rainfall.   All samples taken from localities where the rainfall is 30 inches or more, were classed as from the humid section; those from localities where the rainfall is between 30 and 22 inches as from the sub-humid section; and those from localities where the rainfall is less than 22 inches as from the semi-arid section.

5. It was found that in the humid section the surface of the cropped soil had lost one-third of the nitrogen as compared with the surface soil of the native sod.   The fields in alfalfa contained 14.3 per cent less nitrogen than the native sod, and 21.6 per cent more than those fields which had been cropped to grain.   In the subsurface 7 to 20 inches, the changes due to cropping were much less than in the surface, and in the subsoils there were no changes that could be attributed to the methods of cropping.

6. In the sub-humid section the fields cropped to grain lost one-fourth of the nitrogen as compared with the surface soil of the native sod. The alfalfa fields contain 5 per cent less nitrogen than the native sod, but 20 per cent more than the fields in grain. In this section the changes due to cropping are also confined to the surface and subsurface.

7. In the semi-arid section the cropped soil has lost one-fifth of the nitrogen as compared with the native sod. Alfalfa fields contained 15.7 per cent more nitrogen than the soils in native sod, and 30 per cent more than the soils continuously cropped. In this section the significant changes are confined to the surface soil.

8. This comparison shows that there is an unmistakable gain in nitrogen of the soils in the semi-arid section. This may be attributed in part at least to a greater loss of leaves in curing alfalfa in the arid section.

9. It may be concluded that the continuous growing of alfalfa, may not increase the nitrogen content of the soil. The increased crop production which is usually obtained on alfalfa fields when they are plowed up is probably due to the large amount of available nitrogen they contain.

10. In the humid section, the cropped soils have lost 36 per cent of the organic carbon present in the virgin sod and those in alfalfa over 21 per cent. The fields in alfalfa contain 18 per cent more than those continuously cropped to grain.

11. In all sections the changes in the organic carbon content are confined to the surface soil. There is just one exception to this statement. In the humid section, the subsurface of the native sod has a significantly higher carbon content than the alfalfa or cropped soil.

12. In the sub-humid section the cropped soils have lost 28 per cent of the original carbon content and the alfalfa soils 13 per cent.

13. In the semi-arid section, the cropped soils contain 30 per cent less carbon than the virgin soils and the alfalfa soils 10 per cent less. In this section the changes in carbon content differ fundamentally from the changes in nitrogen which, as previously pointed out, show a gain.

14. The phosphorus content of the cropped soil is lower than that of the alfalfa soil, or soil in native sod. Alfalfa removes more phosphorus from the soil than grain crops. The fact that the alfalfa fields do not show a lower phosphorus content than the soils in native sod, may be taken to mean that there has been a transference of phosphorus from the subsoil to the surface. This transference has probably taken place because of falling of leaves. Because of the small per cent of phosphorus and the limits of determinations, this conclusion is not so well substantiated as those in regard to nitrogen and carbon.

15. In the humid section, the surface of the cropped soil contains the same amount of phosphorus as the subsoils. In all other cases, the phosphorus content of the surface soil is higher than that of the subsoils. This would point to a definite lowering of the phosphorus content of the cropped soil in the humid section.

16. In the sub-humid and semi-arid sections, most of the soils contain 1 per cent and more of calcium and nearly all have some calcium in the carbonate form.   In the humid section, alfalfa was found growing on four soils successfully in which the calcium content was less than 0.5 per cent.   The calcium content in most soils varies from 0.50 to 1 per cent, and in the majority the carbonate form of the calcium is absent.

REFERENCES

(1) ALWAY, F. J.   1909   Changes in the Loess soils of Nebraska caused by cultivation. Neb. Agr. Exp. Sta. Bul. 111.

(2) ALWAY, F. J., AND PINCKNEY, R. M.   1909   On the relation of native legumes to the soil nitrogen of the Nebraska prairies.   *In* Jour. Indus. Engin. Chem., v. 1, p. 771.

(3) LYON, T. L., AND BIZZELL, J. A.   1913   Experiments concerning the top-dressing of alfalfa.   N. Y. (Cornell) Agri. Exp. Sta. Bul. 339.

(4) RUSSEL, E. J.   1908   The nitrogen problem in crop production.   *In* Jour. Roy. Agr. Soc., v. 69, p. 109.

(5) RUSSEL, E. J.   1912   Soil Conditions and Plant Growth, p. 86.   London.

(6) SHUTT, F. T.   1910   Some characteristics of the prairie soils in Canada.   *In* Jour. Agr. Sci., v. 4, p. 335–357.

(7) SNYDER, HARRY   1906   The loss of nitrogen from soils.   *In* Minn. Agr. Exp. Sta. Bul. 194, p. 188–194.

(8) STEWART, ROBERT   1910   The nitrogen and humus problem in dry farming.   Utah Agr. Exp. Sta. Bul. 109.

(9) SWANSON, C. O., AND LATSHAW, W. L.   1916   Chemical composition of alfalfa as affected by stage maturity, mechanical losses and conditions of drying.   *In* Jour. Indus. Engin. Chem., v. 8, no. 8, p. 726.

(10) WARREN, JOSEPH A.   1909   Notes on "The number and distribution of native legumes in Nebraska and Kansas.   U. S. Dept. Agr. Bur. Plant Indus. Circ. 31.

(11) WHITSON, A. R., AND STODDART, C. W.   1908   Factors influencing the phosphate content of soils.   Wis. Agr. Exp. Sta. Res. Bul. 2.

(12) WHITSON, A. R., STODDART, C. W., AND MCLEOD, A. F.   1906   The nitrogen content of soils as affected by cropping.   *In* Wis. Agr. Exp. Sta. 23rd Ann. Rpt. p. 160–170.

(13) WHITSON, A. R., STODDART, C. W., AND MCLEOD, A. F.   1907   Nitrogen content of soils as affected by methods of farming.   *In* Wis. Agr. Exp. Sta. 24th Ann. Rpt. p. 254.
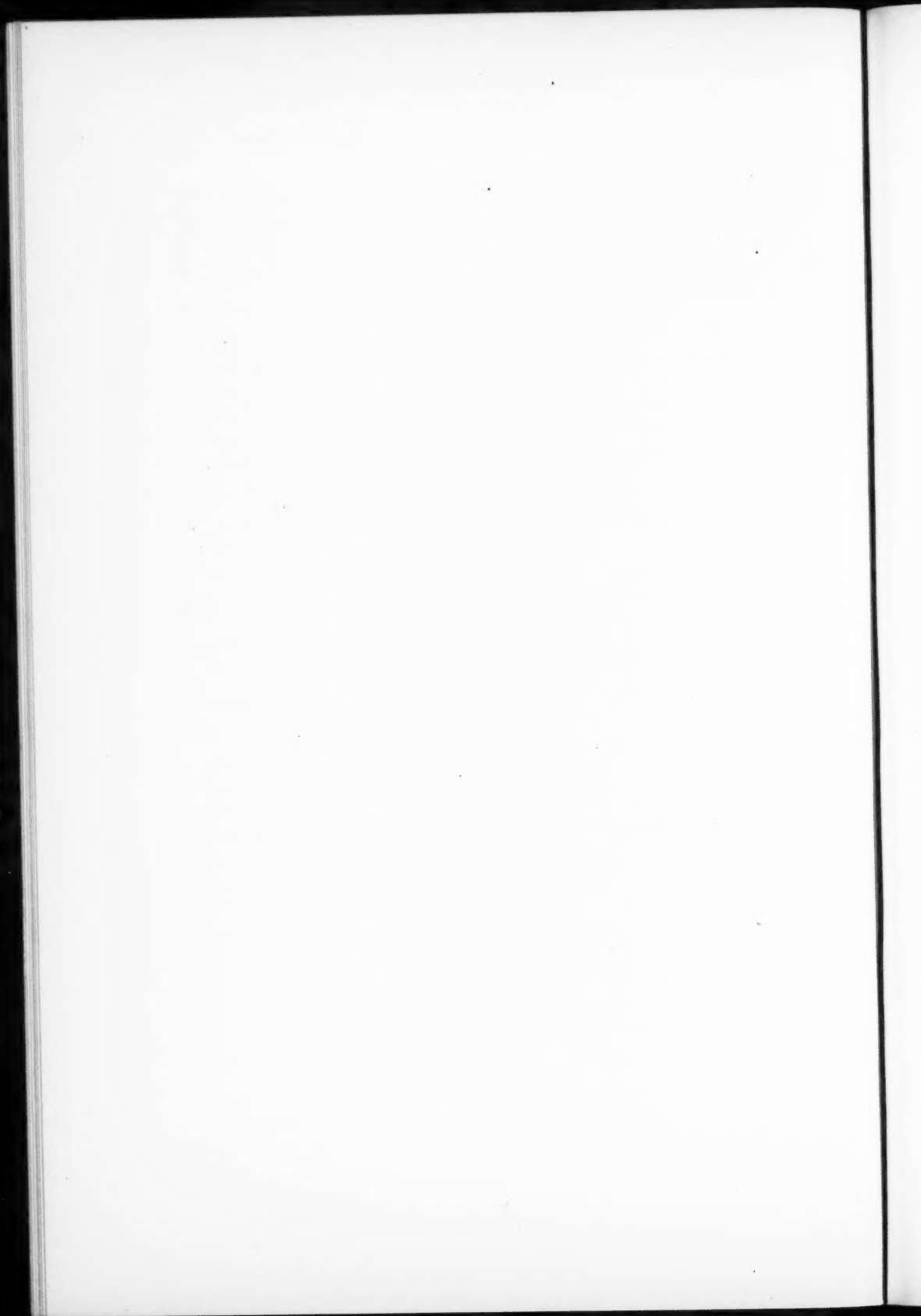
ACTIVITY OF SOIL ACIDS

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Technically the activity of an acid is measured by the concentration of hydrogen-ions which it gives. Activity is determined, therefore, by solubility and ionization.

It would be rather presumptive, however, to say that the activity of the acids present is the only factor to consider, in the study of soil reaction. Soils are very complex and may contain a large number of acids and acid salts, as well as a great variety of bases. The interrelationships of the various soil acids and bases is also extremely complex, and very difficult to point out in specific terms.

There are at least two distinct causes which have been given for the acid condition of soils. One theory is that soil acidity is not due to real acids but that it is a physical phenomenon which has been called adsorption. The other theory which is subdivided into two, is that soil acidity is due to actual acids, some holding that these acids are primarily of organic origin but more believing that the acids are mostly of mineral origin.

METHODS

There are standard methods for measuring the activity of acids but most of them are not easily adapted to soils. Truog (11) has proposed a method which depends upon the competition of soil acids with a standard acid (acetic) for base. It has not proved very satisfactory so far as tested in this laboratory. The method used in this work was designed primarily for the determination of the amount of lime taken up by acid soils and is not presented as especially adapted to a determination of acid activity. But it gives some valuable information on this phase of the problem and hence the results obtained are presented in the following pages.

Such degrees of activity as the method detects depend upon the rate of reaction of acid soil and pure calcium carbonate brought together in water suspension and thoroughly mixed by constant shaking. The carbon dioxide is removed as rapidly as evolved, absorbed in sodium hydroxide and titrated at suitable intervals. This is a modification of the Tacke method (10), the details of which are given in a previous discussion of acidity methods.

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In general there are two types of acidity methods applied to soil work. By one the concentration of hydrogen-ion is determined. This is active acidity which may cause direct toxicity. The other type determines the amount of base taken up by acid soils. Most methods come in this latter class. Such methods may include in their results all active acids capable of giving a high concentration of acid ion, and also all those acids which may be capable of reacting but give only neutral indications with indicators. A good example of such acids is potassium acid phthalate, which is more properly speaking an acid salt, but nevertheless it reacts with its full equivalent of base. Insoluble acids and proteins might be expected to behave in much the same way, though reacting more slowly.

It would seem that information in regard to acid soils is not complete until both its degree of acidity and its capacity for taking up lime are understood. Unfortunately, no one method combines these two phases of the question in one determination.

TABLE 1

Lime requirement at intervals of 3, 6, 9 and 21 hours

	3 HOURS	6 HOURS	9 HOURS	21 HOURS	TOTAL
Soil 1					
Loam.....................	5,000 lbs.*	6,100 lbs.*	6,500 lbs.*	7,000 lbs.*	
Increase.................		1,100 lbs.	400 lbs.	500 lbs.	7,000 lbs.
Per cent of total...........	71.5	15.8	5.6	7.1	100

* These results are all expressed as pounds per acre, of calcium carbonate

Practically all methods permit the reaction of readily active acids. There is, however, a great variation in their capacity to show a reaction with slowly active acids. This is evidenced by the fact that some methods show two or three times the lime requirement of others. The point of equilibrium and the rapidity with which reactions occur are determined many times not primarily by the activity of the acids but by the more or less violent actions of heat and strong bases and also by the mass law. When one product of the reaction is removed, equilibrium represents a more advanced stage of decomposition. Such hastening of the reaction as occurs from the removal of a product of the reaction is perfectly legitimate. Any more violent stimulation of the reaction would likely lead to results that would never be obtained under natural conditions in the field. The method selected seems more natural and normal than any other method in common use.

EXPERIMENTAL

In this study the rate of reaction of soil acids in different soil has been compared and this in turn compared with the rate of reaction of the acidity of buffered solutions of known hydrogen-ion concentration. None of the

first soils used were high in organic matter so that the acidity is probably mineral rather than organic. Titrations were made at various intervals, the blank on the soil and reagents being subtracted each time so that the results show the relative reactivity of the different fractions of acidity.

The above table shows that nearly three-fourths of the soil acids had reacted at the end of 3 hours, assuming complete reaction to have taken place in the whole run. During the second 3 hours only a little more than a fifth as much as the first and during the third 3 hours about a third as much as during the second period, reacted. During the last 12 hours only one-tenth as much reacted as during the first 3 hours. These results show that there is a considerable portion of readily reactive acids while there is also an appreciable portion that is quite slowly active. Similar results are shown in table 2.

TABLE 2

Lime requirement at intervals of 5, 8 and 20 hours

	5 HOURS	8 HOURS	20 HOURS	TOTAL
Soil 1				
Loam..............................	5,660 lbs.	6,480 lbs.	7,020 lbs.	
Increase.............................		820 lbs.	540 lbs.	
Per cent of total......................	80.6	11.7	7.7	100

In this test four-fifths of the acidity reacted at the end of 5 hours. At the other intervals the results are very similar to those in the first test, being nearly identical during the last 12 hours of the run. Results with soil 2, which was more clayey than the first, are shown in table 3.

TABLE 3

Lime requirement at intervals of 9, 24 and 36 hours

	9 HOURS	24 HOURS	36 HOURS	TOTAL
Soil 2				
Clay loam............................	4,425 lbs.	5,700 lbs.	6,750 lbs.	
Increase..............................		1,275 lbs.	1,050 lbs.	
Per cent of total......................	65.6	18.9	15.5	100

This soil was run on the basis that nine or ten hours should be long enough to determine all acidity of a degree of activity sufficient to render harmful effects in the soil. One fact is quite noticeable, viz., that acids were less reactive in this soil than in the preceding one. While nearly two-thirds of the acidity reacted at the end of 9 hours, nearly one-fourth as much reacted during the last 12 hours after having run a period of 24 hours. Since this soil was inclined toward a clay texture, it was probably rich in acid silicates and these were evidently slowly reactive. It is probable that during the reaction, hydrolytic processes occurred and perhaps also an exchange of bases, but such reactions have occurred at a progressively decreasing rate.

In table 4 the results of tests of soils low in organic matter and of low lime requirement are given, titrations being made at intervals of 3 hours. Likewise some soils high in organic matter were subjected to the same runs for comparison.

It will be observed that soil 3 acted as though it had a considerable reserve acidity. The lime requirement was fairly high and the last 3 hours of the run gave nearly one-third as much as the first 3 hours. It reacted very differently from No. 4 which had a lower lime requirement. The difference may have been due partly to the amount, as well as kinds of acid present.

TABLE 4

Lime requirement at intervals of 3 hours

	TIME			TOTAL
	3 HRS.	6 HRS.	9 HRS.	
Soil 3				
Sandy loam........................	3,700 lbs.	5,100 lbs.	6,200 lbs.	
Increase.............................		1,400 lbs.	1,100 lbs.	
Per cent of total......................	59.7	22.6	17.7	100
Soil 4				
Sand...............................	800 lbs.	1,100 lbs.	1,100 lbs.	
Increase.............................		300 lbs.	0	
Per cent of tota......................	72.7	27.3	0	100
Soil 5				
Miami silt...........................	1,800 lbs.	2,300 lbs.	2,500 lbs.	
Increase.............................		500 lbs.	200 lbs.	
Per cent of total......................	72.0	20.0	8.0	
Soil 6				
Muck...............................	15,200 lbs.	19,400 lbs.	25,400 lbs.	
Increase.............................		4,200 lbs.	6,000 lbs.	
Per cent of total......................	60.0	16.4	23.6	100
Soil 7				
Loam, organic.......................	12,400 lbs.	14,200 lbs.	17,000 lbs.	
Increase.............................		1,800 lbs.	2,800 lbs.	
Per cent of total......................	72.9	10.6	16.5	100

The first soil evidently had a larger total acidity, though the reactive portion was relatively smaller. The more highly ionized acids should depress the less active ones and the reaction should continue longer for that reason. The second soil which had a lower lime requirement had a smaller depression of ionization of the less active acids, consequently the reaction was nearly complete sooner. Previous data indicate, however, that several hours may be required on some soils before an approximate completion of reaction is reached. It is not believed that a reaction would ever be absolutely complete, as hydrolysis or hydration or other changes in time may develop a new acidity.

It was thought that soils 6 and 7, being very acid and rather high in organic matter, would react for a longer time.   Consequently, they were run a total of 23 hours.   There was a marked distinction between the loam and the muck soil, the latter reacting much more slowly.   This again may be explained as due to depression of ionization of the less reactive acids, especially by the buffering of the organic matter of the muck soil.

The sandy type of soil reacted more readily, since there was less buffering. But silicious soils may have a considerable portion of insoluble and unreactive acids, as the data indicate.

To get a comparison of the relative rates of reaction during the early runs the rate per hour is given in table 5.   This can be obtained only for equivalent periods, since it would obviously be unfair to compare the rate for a

TABLE 5

Rate per hour of reaction

SOIL NO.	FIRST 3 HOURS	RATE PER HOUR	SECOND 3 HOURS	RATE PER HOUR	THIRD 3 HOURS	RATE PER HOUR	FOURTH 3 HOURS	RATE PER HOUR	17 HOURS	RATE PER HOUR
1	5,000	1,666	1,100	366	400	133	500	42		
3	3,700	1,233	1,400	466	1,100	366				
4	800	266	300	100	0	0				
5	1,800	600	500	166	200	66				
6	15,200	5,066	200	1,400					6,000	353
7	12,400	4,133	1,800	600					2,800	165

Per cent of succeeding hours, based on the first hourly rate

	SECOND 3 HOURS	THIRD 3 HOURS	FOURTH 3 HOURS	17 HOURS
1	21.4	8.0	2.5	
3	37.8	29.6		
4	40.0	0		
5	27.6	11.0		
6	27.6			7.0
7	14.5			4.0

3-hour with a rate for a 10-hour run.   Such a comparison gives a standard basis which is not possible in presenting percentages of total acidity, since such totals nearly always depend upon the length of the run.

A very great variation in the rate of reactivity may be observed.   The amount of acidity which reacted during the second 3 hours varied all the way from 14.5 to 40 per cent of that which reacted during the first 3 hours. During the third 3 hours the variation was nearly as great, running from 0 to 29.6 per cent of the amount evolved during the first 3 hours.   The few figures obtained for the very long runs show that the muck was holding out more persistently than those soils which have less organic matter.   This would indicate a comparatively large reserve of acidity for soils high in organic matter.   But mineral soils may have a rather variable reserve, as is apparent

in the case of soil 3, which gave a high run during the third 3 hours. Soil 1 may be noted for its low reserve. The data apparently indicate that the rate of reactivity and reserve acidity does not depend entirely on the type of soil.

Some greenhouse studies were made with lime-treated acid soils in gallon jars. The lime requirement, taken from another study, by the modified Tacke method was 2.75 tons. Lime as carbonate was applied at the rate of 1-ton increments up to 10 tons. At the end of 2 weeks the 1-ton treatment was nearly completely exhausted. By 4 weeks 2 tons were practically exhausted, and with the larger applications, 6 to 10 tons, an amount of carbonate practically equivalent to the acidity was taken up at the end of 2 weeks. The average of all high treatments, 6, 7, 8, 9 and 10 tons, was exactly 2.75 tons used by the soil. The determinations were made by obtaining residual carbonates and subtracting from the treatments.

These are significant figures and indicate rapid reaction between acid soil and lime when no artificial hastening is provided other than intimate contact in the presence of moisture. Reaction was not complete at this point, however, as the average amount of lime taken up by these same pots 21 weeks later was 4.62 tons, or nearly 1.7 times as much. For the sake of comparison, however, it may be observed that while reaction was at the rate of nearly 1.4 tons per week during the first two weeks, it was only 0.09 ton per week during the following 21 weeks. After this if determinations had been made, the reaction rate would have been extremely slow.

These results show quite definitely that the active acids of soils are neutralized rather quickly in the presence of base, but that the same soil continues to decompose carbonates very slowly even when there is no leaching. So far as evidence goes this absorption of base might continue indefinitely.

The same soils were likewise tested for acidity both quantitatively and qualitatively at various intervals. The first qualitative test was not applied until the end of 4 weeks, but at this time the 3-ton treated soil gave a neutral test by the Truog lead acetate method. The soils receiving treatments of 2 tons were slightly acid. The quantitative tests gave similar results. This again indicates that the active acidity was quickly neutralized even though the soil continued to take up a considerable quantity of lime. These data are good evidence that a soil may remain quite active in decomposing base after all appreciable acidity is neutralized.

These results are wholly from the side of the acidity present. But the base used has a very marked effect also, as may be readily shown. Thus while precipitated calcium carbonate applied at the rate indicated as the lime requirement by the Tacke method, and thoroughly mixed with the soil which was moistened to the optimum moisture content, caused the soil to react to give a neutral qualitative test by simply standing 24 hours, three times the amount of natural magnesian limestone did not give a neutral indication even after several days. The fineness of division is a factor in the above results, but the nature of the base is likewise a factor.

Under field conditions lack of mixing and intimate contact, as well as the coarseness of the material used, would undoubtedly result in a rather slow reaction, but even then it may be presumed that the more reactive acids are neutralized comparatively rapidly.

STUDIES WITH KNOWN H-ION CONCENTRATION

By way of comparison with the rate of reaction of acid soils, several buffered solutions were prepared and tested as to their ability to decompose calcium carbonate. First, acetic acid was buffered with potassium acetate, using 0.2 N acid and normal acetate. With an H-ion concentration of 2.2×10^{-5} the full capacity of the buffered acid was exhausted in a 3-hour run, the 10 cc. of acid used liberating 10 cc. of carbon dioxide in the titration. Similar results were obtained when the H-ion was 1.3×10^{-6} and 7.6×10^{-6} in all tests made. Thus carbon dioxide was evolved from calcium carbonate with each concentration used, to the full capacity of the acid present. The neutral potassium acetate alone liberated no carbon dioxide, as would be expected. With phenolphthalein present it was possible to follow the reaction by the pink color which developed at the end of 2 hours, indicating that the acid had been exhausted. The experiment ran an hour longer, however, in all cases before titration.

Another test was made with known acid and hydrogen-ion concentration in the presence of the soil. The effect would then be that of the acid added plus that of the soil acids. Two soils were used, one sandy and low in organic matter, the other containing less sand and higher in organic matter. It was found that the soil exercised no appreciable depressing effect upon the reaction between the acid and the carbonate. With a hydrogen-ion concentration as low as 7.6×10^{-6} the full capacity of the acid to liberate carbon dioxide was exhausted in a 3-hour run, and the second 2 hours gave a practically constant acidity with and without the acid added. In other words, after the first 3 hours the reaction proceeded as though no acid had been added to the soil. Both soils behaved in the same way and although one had a rather high lime requirement, this requirement was not depressed and the full capacity of the acid was exhausted in the first 3 hours. The sandy soil alone liberated 1 cc. of carbon dioxide and the soil plus 10 cc. of N/2 acetic acid, buffered to give a hydrogen-ion concentration of 7.6×10^{-6} liberated 10.3 cc. or only 0.7 cc. short of the theoretically possible amount, from both soil and acid.

Another buffer solution prepared from sodium hydroxide and monopotassium acid phosphate (50 cc. of 0.2 M KH_2PO_4 and 29.63 cc. of 0.2 M. NaOH diluted to 200 cc.) with a hydrogen-ion concentration of 1×10^{-7}, or the same as that of pure water, was used. Likewise (using the Clarke and Lubs (3) formulae again) a concentration of H-ion of 1.6×10^{-6} was prepared. The neutral and nearly neutral solutions did not react to a measurable extent as might be expected.

In the same way, using potassium acid phthalate and sodium hydroxide, H-ion concentrations of 6.3×10^{-5}, and 1×10^{-5}, also 1×10^{-6} were tested. The first two of these reacted liberating 10.1 cc. and 4.7 cc., respectively, of carbon dioxide titrated as N/10 acid. The other concentration did not react, and all reactions were complete at the end of 3 hours. It is probable that the reaction was really complete sooner, as was indicated by the color given to the indicater (phenolphthalein) after one to two hours, but titrations were made only at 3-hour intervals. The above determinations were made primarily to discover what degree of buffering would yet permit of reaction between the acid and calcium carbonate.

With the same idea in view an N/10 solution of glycocoll and also some albumin and casein were tested. All failed to decompose the carbonate. It is noticeable in the above cases that potassium acid phthalate which is neutral to methyl orange will react with carbonate, or sodium hydroxide, and may be titrated with phenolphthalein, while the glycocoll and proteins used, fail to react. It would seem that compounds which contain the amino group must be in the form of an "inner salt," as is sometimes suggested, the amino groups neutralizing the free carboxyl groups. As decomposition occurs in the soil the carboxyl groups must be set free, but whether they remain to react with base is doubtful.

Since all of the buffered solutions tested, if capable of reacting at all, react to completion by the end of three hours or less, meaning that no further decomposition occurs during a subsequent run, it would seem that soil acids may be subject to considerable buffering and yet react with lime at an appreciable rate. Insolubility is probably one of the more important causes for the slow reaction. The prolonged decomposition of carbonate by acid soils is undoubtedly due in part to a continuous hydration of silica, or to the hydrolysis of various alumino-silicic acid salts. It cannot be determined at what point such reactions would cease.' These results would indicate also that even the more actively functioning portion of acidity of most soils may be held at a low ionic concentration due to buffering. The ionic concentrations which have proved capable of reacting with carbonates are lower than have proved injurious to both plants and soil organisms. But the studies of Sharp and Hoagland and Plummer have shown that acid soils may have a higher concentration of acidity than is compatible with the most efficient functioning of many plants and bacteria. But even in quite acid soils organisms may be active locally if in contact with, or protected by such highly buffered materials as the proteins. It is characteristic of emulsoid colloids to act as protective colloids by forming a thin film about the colloidal particles of another substance. Such protection can operate against an acidity as well as to prevent precipitation of the protected colloid. The organic colloids or protein particles may, therefore, serve as centers of bacterial activity, in much the same way as lime particles, though perhaps less effectively.

HOW DO SOILS BECOME ACID?

With the above experimental data as a basis the question of the origin of acid soils may be taken up. The explanation of the development of an acid condition in soils can probably be given only in part. The question may be conveniently discussed under three topics, mineral acids, organic acids, and colloids.

Mineral acids

If it is assumed that the mineral portion of the earth was once a molten magma, then by cooling, igneous rocks were formed and from these by weathering or metamorphic changes, rocks of secondary classification were derived. In this way, together with the accumulation of organic debris, soils were built up. The original magma being primarily a mixture of oxides, and silicates of alumina, soils are of the same general nature. Igneous rocks run as high as 80 per cent silicates and rarely drop below 40 per cent. Some soils are even richer in silica than this, partly because of the leaching and weathering of less resistant constituents.

The formation of soil from minerals has been predominantly a hydration process, supplemented by oxidations and carbonations. Because of the hydration, marked changes occur, not only in weight and bulk but in reaction and in susceptibility to reaction. During the change not only water but oxygen and carbon dioxide are absorbed. Minerals are converted into acid salts, and these constantly undergo further change by disintegration or metathesis. Hydration processes may produce colloids, of which clay is a good example. When an anhydride becomes hydrous it may assume acid or basic properties, of which clay again is an example. According to Loew pure clay is capable of ionizing as both an acid and a base. But under agricultural conditions the acid radicals are replaced by a base, if not naturally, then by the addition of basic material to the soil.

The most important of the soil-forming silicates are the feldspars and feldspathoids. In fact, feldspars constitute about 60 per cent of igneous rocks, and in tracing changes which occur in their weathering, a suggestion as to the origin of acid soils may be obtained.

Starting with the feldspars, the first change which occurs is probably simple hydration which would result in the formation of zeolites or other hydrates. Long contact with water is the only essential for this change to occur. Thus soda feldspar, albite ($Na_2O.Al_2O_3.6SiO_2$) might change to the zeolite, natrolite ($Na_2O.Al_2O_3.3SiO_2.2H_2O$) by hydration and the splitting off of 3 molecules of silicic anhydride (SiO_2). After hydration further changes probably occur rather rapidly. In fact, it is disputed that zeolites exist in soils. But other hydrated silicates do exist.

As the soil is tilled and bacterial activity is increased, the rate of decay of minerals is much increased. Consequently, cultivated soils are likely to be-

come acid much more rapidly. The soil bases are leached as bicarbonates and the production of carbon dioxide naturally stimulates such changes. Thus the loss of lime from the zeolite, chabizite, $(CaO.Al_2O_3.4SiO_2.2H_2O)$ would probably follow or accompany the hydration of the original feldspar. The calcium would thus leach away as bicarbonate, leaving probably some silica, and clay $(Al_2O_3.2SiO_2.2H_2O)$, which, though it probably seldom exists in the soil in pure form, is nevertheless a complex acid salt.

The above reactions are not given as those which must occur but only as typical of those which are likely to occur. The feldspars and other alumino silicates are really salts of various hypothetical silicic acids which are weak acids, and such bases as potassium, sodium and calcium, which are strong bases. It is entirely logical that such salts should be hydrolyzed, leaving the quite insoluble and slightly ionized acid or acid salt to accumulate in the soil, while the soluble base is leached away. Most bases are rather soluble as bicarbonates, and even the silicates of sodium and potassium are highly leachable.

As specific examples there may be mentioned calcium feldspar, which is a salt of alumino-disilicic acid; potash feldspar, a salt of alumino-hexasilicic acid, natrolite and leucite, salts of alumino-tri and alumino-tetra-silicic acids, respectively. The prefixes di-, tri-, etc., refer to the number of silicic acid molecules which occur in the compound. The di-silicic acid, though it might not be obtained in the free state, would represent the combination of two molecules of silicic acid with an accompanying loss of one molecule of water. As hydrolysis occurs, the acids must be partially or wholly freed and, therefore, rendered active and capable of taking up lime or other bases which might come into contact with them. Ash and Ash give a formula $(2H_2O.2Al_2O_3.8SiO_2)$ which is an alumino silicic acid and as salts of such an acid, $(2Na_2O.2Al_2O3.8SiO_2)$ analcine, or $(CaO.Na_2O.2Al_2O_3.8SiO_2)$ andesite. Although the specific formulae are not of great significance they are of value for the sake of illustrating changes which may occur.

It may be observed also that the salts of this acid contain no water, that is the acid is represented as containing only acid (or base) water as opposed to water of crystallization. The results of Conner (4) are likewise significant in this connection. He found that not only the amount of SiO_2 but also the amount of water in the silicates of alumina had a marked effect upon their reaction. Those silicates with very little water or very little of both water and silica were not acid, while those containing considerable of both were highly acid. This would indicate that much acidity might be due to alumino-silicic acid or acid silicates, and that silicic acid is capable of producing a lime requirement in soils.

It is not thought, however, that silicic acid can give a high hydrogen-ion concentration to soils, but the alumino silicic acids by virtue of the insolubility of their salts may liberate stronger acids, and there can be but little doubt that they take up base and are, therefore, partly responsible for a consid-

erable portion of the lime requirement shown by many acidity methods. But it is possible as suggested by MacIntire (7) that silicic acid is really a stronger acid than is commonly supposed. This author has found that large amounts of magnesium carbonate may be converted into silicates in the soil in a very short time. But it is quite possible too that such a silicate would react again in part at least to neutralize stronger acids. Sodium or potassium silicate should yield considerable free base by hydrolysis, and would, therefore, have neutralizing power. Magnesium silicate similarly to calcium should function as a strong base relative to the solubility.

But other, though less abundant, acids may be credited with the major injurious reaction of soils. Sulfuric acid which may result from the oxidation of sulfur-containing minerals such as pyrites, or sulfur-containing proteins, or by the oxidation of free sulfur, produces decidedly harmful effects if base is not present. This is very emphatically demonstrated on ammonium-sulfate treated plots where the cumulative effect of several years has been noted. The same effects may result from the use of potassium chloride. These acids are doubtless sometimes set free through an exchange of bases, such as the substitution of potassium for aluminum in zeolites (if present), feldspars or other complex soil minerals. Parker (9) in particular has observed such substitutions to occur under experimental conditions. The hydrolysis of the aluminum salt would give a highly acid reaction. According to the work of Conner (4) this is the primary cause of acidity on certain soils, and the acidity is reduced by treating the soils with phosphate which removes the aluminum and iron from a sphere of active functioning.

Nitric, though a strong acid, is perhaps not often directly responsible for an injurious soil reaction for two reasons. Nitrates are used largely by all plants and soil organisms, and are rapidly leached from the soil if not used. But leaching removes base and in this indirect way promotes acidity. If the nitrification process were very rapid there would likely result an unusual depletion of soil bases. In this same connection it is worthy of note that no highly soluble, reactive acid can long exist in the free state even in the absence of base, because of leaching. Likewise the salts of such acids in so far as they are soluble, are rapidly leached from humid soils.

A very important acid from the standpoint of plant economy is phosphoric. This is a rather weak acid being only about 17 per cent ionized in an $N/2$ solution. It is not likely however, that any harmful acidity may result from the use of phosphates.

When acidity is designated as a condition which results in the taking up of lime, part of such a lime requirement is undoubtedly not the result of the presence of toxic acids. According to van Bemmelen (1), though zeolitic silicates or other hydrous silicates may take up bases by exchange, not all are absorbed with the same readiness. The order given is potassium, ammonium, sodium and calcium, in descending scale. Calcium is one of the last bases to be held and should accordingly have ample opportunity for leaching,

and it is true in practice that calcium is lost by soil leaching to a much greater extent than any other base.   On this account as well as for economic reasons, lime is the chief base likely to be needed for artificial soil treatment.   Potassium which is used to a larger extent by plants, being absorbed readily, is leached only slightly and most soils except sands contain an abundant supply. The extent of potassium absorption is evident from the fact that in river water there is only about one-third as much potassium as sodium, while in the ocean the ratio has been reduced to one-thirtieth as much (2).   The original soil not only gives up its potassium reluctantly as compared with sodium, but the river silt removes the former base much more rapidly than it does the latter and consequently it is mainly sodium which is carried into the sea.   From the acidity phase of the question the above consideration is significant in that it indicates that at least a part of the base taken up by acid soils is the result of chemical absorption by complex acid silicates, which is a valuable natural check upon the loss of soil bases.

Basic minerals (those having less than 55 per cent of silica) weather much more rapidly than acidic minerals, so-called because of higher silica content rather than because of reaction.   Clays are predominantly acidic and weather very slowly.   According to Clark and Steiger, on the other hand, minerals such as apophyllite, natronlite and pectolite react alkaline when moistened, but such minerals give up their alkalis rather readily.   Practically all minerals are soluble and subject to decay, most of them appreciably so in water, especially in the presence of carbon dioxide.   Organic acids likewise increase the rate of dissolution.   Oxides of iron and aluminum are the most refactory and least likely to be removed by leaching of all minerals occurring in crystalline silicious rocks.   These same minerals, however, undergo many changes of combination and are a continuous possible source of soil acidity if conditions become right, for acid functioning.

In general, it may be said that an injurious mineral acidity is not only possible but highly probable in most acid soils.   Or to state the situation more logically, when there is a toxic acidity in soils, the acid ion probably has its source in a mineral acid and much of the reserve acidity is likewise of the same nature.   Such acids, many of them quite insoluble and not subject to oxidation, must result in a rather stable acidity.   But the concentration of hydrogen-ion which is furnished and the consequent injury to plants or soil organisms is a complicated and as yet not specifically determined problem. According to Truog, it is rather the lime requirement of the plant than that of the soil which is significant.   Such would undoubtedly be true on soils of weakly active acids where bases were lacking.   In the presence of stronger acids in larger amounts it is probably true that a direct injury results to plants from the acids themselves.   Crops often have short stubby and stunted roots when grown in acid soils evidently because the acidity is not favorable to the spreading and elongation of the root systems.   But the effect of reaction upon the microscopic flora of the soil is of just as great significance as is the

effect upon higher plants. Most bacteria do not feed upon bases so that the question comes to be in this case one of reaction rather than of food supply.

Such hydrogen-ion studies as have been made show that there is a more or less definite concentration which organisms are able to endure. Soils are found to have too great an acidity for certain organisms, especially nitrifying and nitrogen-fixing organisms, and under such conditions the specific organism is present only sparsely. Its presence is doubtless due to the fact that there are local alkaline or buffered regions where the organisms may multiply and to the fact that resistant strains tend to develop under acid conditions.

Organic acids

There are two distinct kinds of material which may give rise to organic acids. These are the proteins and the carbohydrates. If the proteins are considered it is found that their acid equivalent depends upon the number of free carboxyl groups, while the net acidity and reaction of the protein depends upon the relative number of carboxyl and amino groups, the one group just about offsetting the effect of the other. Proteins are probably only very slightly ionized, and for that reason would react very slowly with soil bases. But they may be present in the form of an "inner salt" and would therefore react very little with lime, until decomposed.

Proteins are made up of amino acids and when decomposition occurs it is brought about by a hydrolytic process, water being added at the peptide likage, thereby freeing the amino acids. When the decomposition process has proceeded this far there can be little effect toward increasing the hydrogen-ion concentration of the soil. Most of the amino acids such as amino acetic, amino propionic, tyrosine, lysine, arginine, histidine, and phenylalanine have acid ionization constants of an order of magnitude varying from 2×10^{-9} to 1×10^{-14} which is much too weak to have a very harmful effect. The acid constant for carbonic acid is 3×10^{-7} and it would not be expected therefore that the much weaker amino acids would very readily displace carbonic acids from its salts, and thereby use up base. But such reactions do occur and there are calcium and other salts of proteins. But these same amino acids have basic ionization constants of practically the same order of magnitude, the values varying from about 5×10^{-9} to 3×10^{-12}. Some are slightly more acidic than basic, others the reverse, but the sum total effect would be nearly neutral.

The next step in decomposition would probably be the splitting off of ammonia from the amino acids. Taking amino acetic acid as an example, it may readily be seen that the ammonia produced will be fully equivalent to the acetic acid, and the effect upon soil reaction will still remain negative, ammonia and acetic acid having practically the same ionization values. And the common organic acids which might originate in this way are of practically the same strength. Thus acetic, valeric, butyric and propionic acids have

constants of the order of magnitude of $1.6 \cdot \times 10^{-5}$. These same fatty acids might be formed just as well from carbohydrates and in that case no ammonia production would accompany the process, and whatever acids were produced could increase the actual acidity of the soils. Such acids are strong enough to give an appreciable hydrogen-ion concentration and would really be injurious in case they were stable. But it is a well known fact that many organic acids are quite volatile or readily oxidized, and it is questionable if under any condition favorable to crop production there would be a noticeable accumulation of organic acids. Organic acids are suitable sources of energy for certain soil organisms and when aeration is provided they are probably oxidized about as they are produced. Such data as are available indicate this to be true.

But considering again the effect of the ammonia which is liberated along with the fatty acids in protein decomposition, as well as other nitrogen bases which might occur, it is very evident that nitrification must occur sooner or later. This not only removes base, but produces strong nitric acid at the same time and should, therefore, have a marked effect upon soil reaction. In many soils there is several times as much nitrate produced as is used by growing crops. The nitrates are readily leached and in this way remove large amounts of base and, therefore, tend to cause base-poor soils. This is another reason why tilled soils may become acid rapidly. Virgin soils nitrify much more slowly as a rule, and there is, therefore, more of the buffering effects of accumulated proteins as well as less leaching of bases in the form of nitrates.

The general indication is, therefore, that organic matter is not likely to produce a harmful soil acidity. During the wet season when the soil is saturated and oxidation cannot proceed readily, there may be an accumulation of organic acids. But when dry conditions prevail these acids rapidly oxidize and disappear. The general effect of organic material would seem to be to keep down acidity rather than to increase it. Proteins are good buffers, which means that they are capable of combining with either acid or base without changing in reaction. If the reaction is with stronger acids there is a reduction of the acidity in terms of hydrogen-ion. If they combine with base, it is only prevented from leaching, since many protein salts as well as organic acid salts are quite insoluble and non-leachable. But decomposition will finally liberate the base and it may then neutralize a strong acid. Thus calcium citrate or oxalate should be just as effective as lime in neutralizing sulfuric acid, since either of these organic acids would be expected to disappear from the soil quite rapidly when liberated.

The question may arise why peat and muck soils should become very acid. In reply it may be stated that conditions are very different here from those found in ordinary soils. The content of organic matter is very high, aeration is usually not good, since such soils occur only in low and wet places. And mineral bases are usually not present. Where bases are present acidity does

not occur. Such soils, therefore, become acid because conditions are extremely favorable to the large production of organic acids, with little opportunity for their removal. In general, such soils would be expected to take up large amounts of lime, even though the hydrogen-ion concentration might not be high.

Colloids and soil reaction

As stated above, soil acidity has been attributed to adsorption of bases by colloids, though this explanation is usually thought to be entirely inadequate. A question naturally arises as to why and how colloids may contribute to acidity. The answer may possibly be found in the size of colloid particles.

It may be stated that practically any material may form a colloid if obtained in the proper state of divisions. Colloidal particles are larger than ordinary molecules and yet not large enough to settle out. The average molecule is estimated at 2×10^{-8} cm. while the range of colloids is usually placed at from 0.1μ to 1.0μ μ, which is 1×10^{-3} to 1×10^{-6} cm. There may be, therefore, several thousand molecules in one colloidal particle. On the other hand, single molecules, such as the hemoglobin molecule which is 2.3 to 2.5×10^{-6} cm. in diameter, may be large enough to form a colloid.

The effect of a colloid, therefore, is greatly to increase the surface of any liquid in which it may be suspended. And since adsorption is a surface phenomenon, the relation to colloids becomes evident. This relationship may be further demonstrated as follows (5): Suppose that 1 cc. of a substance is reduced to cubes 0.1μ on each edge and suspended in water. The volume of one cube becomes $0.1\mu^3$ or 1×10^{-15} cc. The number of particles, therefore, is 1×10^{-15}. The surface of one particle is $6 \times (0.1\mu)^2$ or 6×10^{-10} sq. cm. and the total surface is 6×10^5 sq. cm. The surface of the original cube was only 6 sq. cm. Therefore, the surface of the water suspension of the divided particles is increased 100,000 times. The surface tension of water expressed in dynes per square centimeter has likewise been increased 100,000 times. Then since those substances which reduce the surface energy tend to accumulate in the surface, a much larger quantity of substances low in surface energy can be adsorbed. According to the adsorption theory of soil acidity, bases reduce the surface energy and therefore, are adsorbed and removed as though they had been taken up by acids.

If this were the correct theory for soil acidity, such a phenomena could be produced by any sort of finely divided material, and it should be possible to create an acidity, increasing or decreasing it at will by varying the quantity and size of colloidal particles in suspension. No data of this kind are available.

And again it may be observed that such substances as fatty acids and other organic materials have a very low surface energy, acetic acid having an energy of 23 dynes compared to 73 dynes for pure water at the temperature of 20°C. If organic acids did occur in soils they would, therefore, be adsorbed to a much greater extent than mineral bases. There seems to be

no surface tension data for the alkalis, but the surface tension of mineral acids, such as sulfuric and hydrochloric and their salts, is greater than that of pure water, varying from about 74 to 80 dynes per square centimeter. Evidence, therefore, seems to be rather against the theory that the adsorption of bases is responsible for what is commonly called soil acidity, though it is entirely possible that true acids or bases present in the soil from whatever source may be adsorbed and held in a very similar way as hygroscopic or soil film water.

There is no question but that colloids of both mineral and organic nature are present in abundance in soils, and that they play a part in soil acidity through chemical action. Colloids are natural phenomena of rock formation. The original molten magma, which was a mineral solution, contained the various ions which reacted with each other to form the complex silicates of aluminum, such as feldspars and feldspathoids which by subsequent alterations, produced soils. In the cooling of the magma various minerals, according as their fusing temperature is low or high, separated out at certain intervals, the feldspars and silicic anhydride being probably among the last to separate. If the cooling was very rapid a glass or highly viscous colloid separated. If the cooling was slow enough, crystallization occurred. As a matter of fact, the formation of a colloid may be thought of as a process of crystallization in which most of the crystals formed are infinitely small.

The most important mineral colloids of soils are the clay and zeolites and similar hydrated silicates or secondary products of rock formation, and to a less important extent hydroxides of iron and alumina and sometimes silicic acid. It is characteristic of colloids to be rather highly hydrated, the water being held loosely, chemically combined and ionizing sometimes as an acid and again as a base. The amphoteric nature of colloids is due to their ability to undergo the two kinds of ionization, the particular kind undoubtedly depending on several factors. The presence of strong acids would, of course, favor the basic ionization.

There is little question but that colloids exhibit a capacity for taking up bases. But it is seldom that a colloid may give a toxic hydrogen-ion concentration, and whether there is a physical adsorption by colloids is an open question. According to Langmuir (6) adsorption is entirely chemical, the adsorbed material being held by chemical forces exerted upon active groups such as $^-$OH, $=$ CO, $-C\diagdown^{O}_{O-,}$ tc. present in the adsorbed molecules. This chemical force is active in the surface layer of the adsorbing surface. The adsorption theory of Harris depending upon the Helmholtz double layer hypothesis is likewise really chemical, since there is an exchange of ions and chemical forces operating to hold the adsorbed ions. It may be considered at least true that a colloid will take up base in so far as it ionizes as an acid, but such a reaction is only an ordinary chemical phenomenon.

Practically all organic materials of the soil are colloids, and mostly of the emulsoid type. An important distinction between suspensoid and emulsoid colloids is found in the amount of water of hydration. Thus albumin may hold many times its weight of water. Mineral colloids, on the other hand, rarely hold more than 10 to 20 per cent as bound water. This affinity for water is responsible for a number of colloidal properties. Thus the swelling of soils is due to the taking up of water by soil colloids, and the shrinking and cracking is due to reverse conditions, loss of water. The large amount of water of emulsoid colloids also causes the colloid to have nearly the same index of refraction of light as the pure water in which it is dissolved, which means that the solvent and solute are nearly homogeneous. The large amount of water present causes such colloids to function as a solvent for mineral nutrients.

The reaction of most colloidal material of the soil is nearly neutral or only slightly acidic. Partly for this reason and partly because of food supply organisms are more numerous and active in the presence of organic matter. It is possible, however, to have a highly organic soil which is not active bacteriologically. This condition occurs in peats and forest soils and is usually attributed to acidity. Acid-resistant fungi such as molds are characteristic of such soils.

It is probable that in mineral soils, organic materials are present as protective colloids about the fine mineral particles of the soil mass. In this organic layer or film, organisms are active, and it is likewise here that soil reaction functions. It is generally found that burning a soil destroys its acidity and makes it an especially suitable medium for bacterial action. This is likewise easily explained when the nature of colloidal material is understood. Mineral silicates and also organic colloids are dehydrated by burning. Since the colloid owes its acid properties to its water of hydration, it is quite natural that acidity should be destroyed by heat. Other stronger acids such as nitric would be either volatilized or converted into harmless salts by bases in the ash of the organic constituents. Then, too, since colloids have the property of swelling and because of their fineness of division, of filling all interspaces of soil particles, aeration of the soil is much increased by burning. Ignited soil then becomes an excellent medium for aerobic organisms and is often used for their study in the laboratory.

CONCLUSION

In the natural processes of soil formation such as the kaolinitization of feldspars, bases are removed, tending to leave acid alumino-silicates, or silicic anhydride capable of rehydration to acid silica, with the result that mineral soils may have a comparatively large reserve of slowly reactive acids. Such acids are capable of a more or less indefinite but continuous decomposition of carbonate.

Toxic acid reactions, however, are more probably due to the presence of more soluble and highly ionized acids, such as sulfuric or hydrochloric, nitric, etc. usually introduced by some sort of fertilizing treatments. Such acids exert toxic action because of previous removal of base primarily by leaching. It is only seldom and in highly organic, poorly drained soils that organic acids accumulate to a detrimental extent. This may be observed in peat soils but not often in soils of mineral types. In fact, organic matter quite likely depresses the more active acidity by buffering and by supplying base in the form of ammonia or its derivatives.

The phenomena of absorption of base, commonly classed as acidity, is a very desirable action resulting as it does in the fixation of elements otherwise lost in the drainage. Even though fixation occurs automatically, the hydration and hydrolytic changes which are constantly occurring permit base weathering with the loss of essential elements and an increased tendency to give an active soil acidity.

The method of formation of soils and the susceptibility to erosion and leaching are probably important factors in the production of acid soils. Thus soils formed by the slow weathering and accumulation of rock debris, *in situ*, would allow ample opportunity for base leaching even though large amounts were originally present. On the other hand, glacial soils being deposited more rapidly if they contained basic material originally, would probably not become acid so quickly, that is, they were not extensively base-leached during the process of formation.

In a somewhat similar way tillage must increase the tendency to develop acidity, for crops remove base, and tillage increases bacterial activity, thus producing more carbon dioxide to facilitate leaching. Tillage also exhausts organic matter, thus removing part of the soil capacity for holding base and destroying its buffering propensities. Active nitrification is especially exhaustive of base. A very effective safeguard against an injurious acidity should be to maintain an adequate supply of organic matter in the soil.

SUMMARY

1. The modified Tacke method is capable of adaptation to determinations of the relative activities of different fractions of soil acidity.

2. The more reactive acids, those capable of giving a toxic concentration of hydrogen-ion, react rather quickly. This has been proved by the application of lime to acid soil in successive increments and applying a qualitative test to determine at what stage a neutral soil reaction may be obtained.

3. Soils may contain a large reserve of acidity, which might be described as potential rather than active, but which is, nevertheless, capable of slowly decomposing carbonates.

4. Rather highly buffered solutions react rapidly with calcium carbonate, even in the presence of soil, indicating that even the more active fractions of the soil acids may be considerably buffered.

5. Protein materials and amino acids so far as tested, previous to decomposition in the soil, do not react readily with carbonates.

6. Knowledge of acid soils is considered more adequate when something is known of the activity of the acids, as well as of the total potential acidity commonly determined, more or less inaccurately. It is not the capacity of a soil to decompose lime, but rather the intensity of decomposition which is most highly significant.

REFERENCES

(1) BEMMELEN, J. M. VAN   1877   Das Absorptionsvermögen der Ackererde.   *In* Landw. Vers. Stat., Bd. 21, p. 135–194.

(2) CLARK, F. W.   1900   Contributions to Chemistry and Minerology. U. S. Geol. Survey Bul. 167, p. 156.

(3) CLARK, W. M., AND LUBS, H. A.   1916   The colorimetric determination of hydrogen-ion concentration and its application to bacteriology.   *In* Jour. Bact., v. 2, no. 1, p. 1–34; no. 2, p. 109–136; no. 3, p. 191–236.

(4) CONNER, S. D.   1916   Acid soils and the effect of acid phosphate and other fertilizers upon them.   *In* Jour. Engin. Indus. Chem., v. 8, no. 1, p. 351.

(5) GETMAN, FREDRICK, H.   1918   Theoretical Chemistry.   John Wiley and Sons, Inc. Chicago.

(6) LANGMUIR, I.   1918   The adsorption of gases on plane surfaces of glass.   In Jour. Amer. Chem. Soc., v. 40, no. 9, p. 1361.

(7) MACINTIRE, W. H.   1914   The non-existence of magnesium carbonate in humid soils. Tenn. Agr. Exp. Sta. Bul. 107, Tech. ser. No. 3.

(8) MACINTIRE, W. H.   1916   Factors influencing the lime and magnesia requirement of soils. Tenn. Agr. Exp. Sta. Bul. 115.

(9) PARKER, E. G.   1913   Selective absorption by soils.   *In* Jour. Agr. Res., v. 1, p. 179.

(10) STEPHENSON, R. E.   1918   Soil acidity methods.   *In* Soil Sci., v. 6, no. 1, p. 33.

(11) TRUOG, E.   1916   A new apparatus for the determination of soil carbonates and new methods for the determination of soil acidity.   *In* Jour. Indus. Engin. Chem., v. 8, no. 4, p. 341.

(12) TRUOG, E.   1918   Soil acidity, I.   Its relation to the growth of plants. *In* Soil Sci., v. 5, no. 3, p. 169.
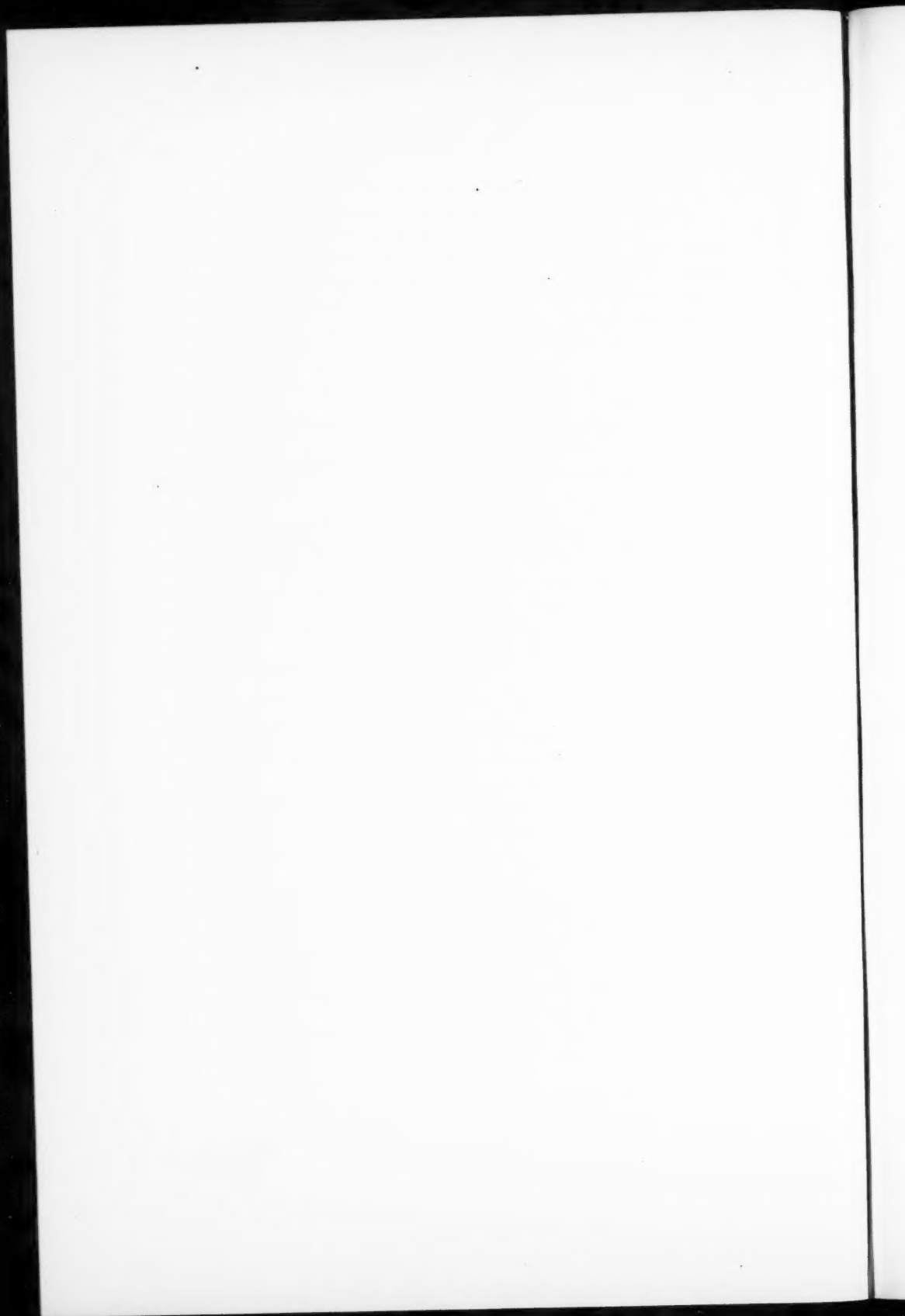
THE VOLUMETRIC DETERMINATION OF SULFATES BY OXIDATION OF BENZIDINE SULFATE WITH KMnO$_4$

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The main principles of the method here given are similar to those proposed by Raiziss and Dubin (2), but there is much modification of details in order to increase accuracy. Its essentials are: first, the isolation of SO$_4$ as the insoluble benzidine salt, second, the measurement of the amount of combined benzidine by titration with standard permanganate. This is carried out at boiling temperature with excess of KMnO$_4$. The excess is removed by standard oxalic acid, and the final titration completed with KMnO$_4$. In this way inaccuracies due to variations in temperature, time, concentration, and incompleteness of oxidation are largely eliminated. Raiziss and Dubin gave some attention to the effect of these variables, but did not define precisely the conditions required for high accuracy.

For the experimental work here reported a solution of benzidine hydrochloride containing 8 gm. in 1 liter was used. Two solutions of K$_2$SO$_4$ were used as source of SO$_4$, one containing 1 mgm., the other 0.1 mgm. SO$_4$ in 1 cc. Titrations were made with N/20 KMnO$_4$ and against this N/20 oxalic acid was used. The exact strength of KMnO$_4$ was found by Soerensen's sodium oxalate.

In order to determine the effect of varying conditions, 10-cc. portions of the benzidine solution were titrated with N/20 KMnO$_4$ under varying conditions.

It was found that temperature should be kept constant in order to secure concordant results, while variation in free H$_2$SO$_4$ is not important. Variation in volume has somewhat the same effect as variation in temperature due to lowering of temperature by the cold KMnO$_4$ when the volume of the solution to which it was added was small. To eliminate as much as possible the effect of variation in temperature and volume it was decided to start the titration with a constant volume of 100 cc., containing 5 cc. H$_2$SO$_4$ and heat in a boiling water bath, which would require no special apparatus or attention to maintain a constant temperature.

Variation in the amount of benzidine in the solution to be titrated was found to vary the factor for converting cubic centimeters of KMnO$_4$ used to SO$_4$, if the method of titration given by Raiziss and Dubin were used. This method does not carry the reaction to completion, especially if much benzi-

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dine is present. Christie and Martin (1) applied this method to the deter-
mination of SO_4 in soil extracts, using the factor 0.15 to convert cubic
centimeters of N/20 $KMnO_4$ to mgm. SO_4. With this factor, small amounts
of SO_4 are underestimated, while large amounts are greatly overestimated.
Applying this method on known amounts of sulfate, the factor for N/20
$KMnO_4$ was found to be as follows: for 1 mgm. SO_4 0.179; for 2 mgm. SO_4,
0.152; for 5 mgm. SO_4, 0.133. With the last it was impossible to carry the
reaction to completion in any reasonable time. A slight excess of $KMnO_4$
soon disappears, and this may be repeated indefinitely for some time.

When the new method—excess $KMnO_4$, digesting hot, adding excess
oxalic acid, and completing the titration with $KMnO_4$—was used, the factors
found were: for 1 mgm. SO_4, 0.124; for 2 mgm. SO_4, 0.122; for 5 mgm. SO_4,
0.122. Even with this method the reaction is not quite complete in the
presence of 5 mgm. SO_4. With amounts less than 2 mgm. SO_4 the end point
is quite sharp. In fact it is the same as in the titration of pure oxalic acid.
The titration is completed in a few seconds, and an excess of 1 drop $KMnO_4$
colors the solution pink for some time.

Imperfect washing of the precipitate of benzidine sulfate may cause many
errors in the determination of SO_4 due to the uncombined benzidine remain-
ing in the precipitate. Considerable time and effort were spent in the endeavor
to improve the washing process. The precipitate is somewhat soluble in
water, more so as the water is warmer, and considerably soluble in alcohol.
Addition of small amounts of acids, hydrochloric, nitric, phosphoric or acetic,
to the wash water, seemed to increase the solubility of the precipitate. It is
decomposed by dilute alkalies. A saturated water solution of benzidine
sulfate does not dissolve the precipitate, but instead increases its amount,
thus causing plus error. It was finally decided that water was the only
feasible washing agent and that the amount used must be very small and as
cold as possible in order to avoid solution of the precipitate.

All the details of the procedure are given in the following description of
the method. At best it must be admitted that it is somewhat empirical and
has serious limitations, yet it is rapid and sufficiently accurate for most work
on· soil extracts, biological fluids or other similar solutions containing small
amounts of sulfates.

PREPARATION OF THE SULFATE SOLUTION

The solution should be free from organic matter, which hinders complete
precipitation; iron, which causes various irregularities; phosphate ion, which
is precipitated by benzidine; nitrates, which increase the amount of precipi-
tate and other oxidizing agents or heavy metals. It may be prepared by
evaporating the soil extract or similar solution to dryness in a porcelain casse-
role and igniting. One or two cubic centimeters of nitric acid added before
evaporating will greatly assist in burning off organic matter. If there is much,

it will be worth while to repeat the evaporation with more nitric acid. If desired 2 to 5 mgm. $Mg(NO_3)_2$ may be added. This is desirable, especially if there are not enough bases present to prevent volatilization of SO_3 on ignition. Also the solution may be freed of organic matter by evaporating to dryness with nitric acid in a flask, and again adding nitric acid and evaporating, repeating till the residue is white. Then it must be once more evaporated with hydrochloric acid to remove nitric. Now add dilute HCl, about 2 cc. 0.1 N and a little water, 5 to 10 cc., to bring the sulfates into solution. In general the solution is now ready for precipitation with benzidine; a small amount of suspended matter such as SiO_2 will do no harm. Iron or phosphate if present, should be removed, as follows.

REMOVAL OF IRON AND PHOSPHATE

Add a few drops dilute solution $FeCl_3$, then dilute NaOH till distinctly alkaline to phenolphthalein. Filter and wash precipitate free of sulfates. The solution is now ready for the benzidine method.

THE METHOD

The quantity of SO_4 should not be over 3 to 4 mgm. Less than 0.5 mgm. is too small for accurate results. More than 4 mgm. makes it cumbrous and inexact. The total volume should be 10 to 25 cc., most conveniently handled in a 200-cc. conical flask. Add a drop of phenolphthalein, then dilute NaOH till alkaline. Neutralize with 0.1 N HCl and add 0.1 cc. in excess for each 5 cc. volume of the solution. Keep as cold as convenient, and add 5 cc. benzidine solution (8 gm. benzidine hydrochloride to 1 liter). Shake a few times during 15 to 30 minutes, then filter on a Gooch crucible prepared with a thin felt of well washed asbestos. The felt should be as small as will hold the precipitate in order to avoid unnecesssary washing. The asbestos should have been previously digested hot with 5 per cent H_2SO_4 and excess of $KMnO_4$ to remove oxidizable matter, then treated with excess of oxalic acid and washed free of soluble matter. Rinse the flask three times with 5-cc. portions of cold pure water, sucking out the liquid each time before adding the next wash. Wash down the inside of the crucible once with a fine jet from the wash bottle. Return the felt and precipitate to the flask, rinsing the crucible with a little water. Add 1 cc. 10 per cent NaOH, place the flask in a boiling water bath a few minutes to decompose the precipitate. After the flask and contents become hot add 10 cc. dilute H_2SO_4 (equal parts acid and water) and hot water to bring the total volume to about 100 cc. Return to the hot water bath. When hot, run in N/20 $KMnO_4$ gradually till the yellow color disappears and the red fades slowly, add at least 5 cc. in excess and return to the boiling water 10 minutes. The time should be observed carefully, as change in time varies the amount of $KMnO_4$ required. At the end of the time remove the flask from the bath and add 10 cc. N/20 oxalic acid. After

the precipitated manganese has redissolved and the solution is colorless, complete the titration with the $KMnO_4$. ˙One drop in excess should give the solution a pink color permanent for some time. However, if more than 3 mgm. of SO_4 were taken, oxidation will be incomplete under these conditions and the pink color will soon fade. The total number of cubic centimeters of $KMnO_4$ used, less 10, multiplied by 0.12 gives the number of milligrams of SO_4 in the solution taken. On account of the inadequate washing and other variables a blank determination will require 0.3 to 0.7 cc. N/20 $KMnO_4$. Using the factor 0.12, quantities of SO_4 less than 1 mgm. will be likely to be slightly over-estimated, while quantities over 3 mgm. are likely to be under-estimated.   In order to determine the exact factor to be used, it is only necessary to run through the process with a known amount of sulfate of about the same magnitude as that in the substance analyzed.

For the sake of completeness, the following notes are added. Theoretically 1 SO_4 required about 2.72 benzidine hydrochloride to precipitate it. The solution used contains 40 mgm. in 5 cc., which should precipitate 14 mgm. SO_4, much more than can be well handled. A considerable excess of the reagent is desirable, but the amount used is ample. However, it was found by direct experiment that a much larger excess only slightly influenced the result.

A saturated water solution of benzidine sulfate for washing the precipitate is not successful, probably on account of the large variation of solubility with variation of temperature.

Free acid should be kept near the limits suggested, as the precipitate is notably˙soluble in dilute acids.

Iron in the solution makes it difficult to adjust the acidity properly and develops various colors leading to erratic results.

Phosphate is precipitated by benzidine less readily than sulfate, especially in the presence of free acid.   But it is so difficult to adjust the acidity in order to precipitate SO_4 while holding PO_4 in solution, that it is best to remove PO_4 if the amount present is more than 0.3 mgm. or sufficient to make a visible precipitate when made alkaline.

The degree of accuracy obtainable is indicated by the following figures:

SO_4 TAKEN	SO_4 FOUND BY USE OF FACTOR 0.12
mgm.	mgm.
0.5	0.492
0.5	0.528
1.0	0.962
1.0	0.996
2.0	2.040
2.0	2.016
5.0	4.860
5.0	4.980

SUMMARY

1. The method proposed by Raiziss and Dubin is faulty in that the conditions are not sharply defined, so that the ratio of SO_4 to $KMnO_4$ is not constant, but varies with the amount of each, and with other varying factors.

2. Temperature and volume are the most important factors which should be kept constant.

3. The method of Raiziss and Dubin never carried the oxidation of the benzidine to completion, and the less so, as more benzidine was present.

4. The new method, here proposed, secures complete oxidation, a sharp end point, and a constant ratio of SO_4 to $KMnO_4$, by proper control of conditions.

5. A perfectly satisfactory method of washing the precipitate of benzidine sulfate has not been found.

6. The method is described in detail. It is rapid and accurate if properly executed.

7. The solution for precipitation of benzidine sulfates should be nearly free of organic matter, which may be removed by evaporation with aqua regia to dryness in a flask, or by evaporation to dryness and ignition in a porcelain dish. Iron, nitrate, phosphate, and heavy metals should be absent.

REFERENCES

(1) CHRISTIE, A. W., AND MARTIN, J. C. 1917 The volumetric determination of sulfates in water extracts of soils. *In* Soil Sci., v. 4, no. 6, p. 477.

(2) RAIZISS, G. W., AND DUBIN, H. 1914 A volumetric method for the estimation of total sulfur in urine. *In* Jour. Biol. Chem., v. 18, no. 2, p. 297.
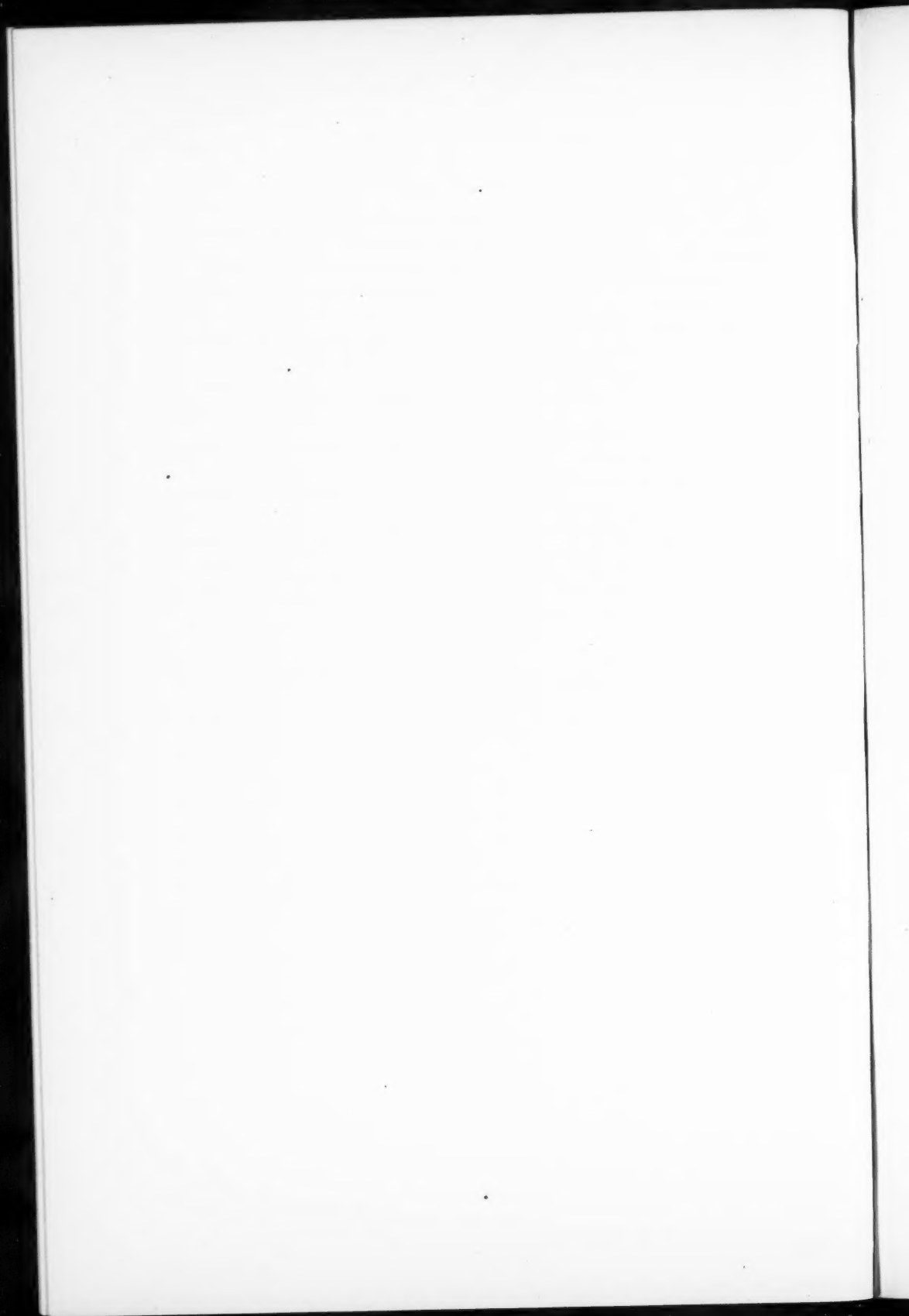
VEGETATIVE GROWTH IN SOILS CONTAINING CRUDE PETROLEUM

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The writer had occasion during the past year to make some investigations concerning the effect upon vegetative growth of crude petroleum oil mixed with soil. The occasion for the oil coming in contact with the soil was due to breaks in cross-country pipe lines which permitted some oil to escape to the surface of the ground and spread, or be carried by high water, and later backed over the lower lands. Investigations of the soil and crops said to be damaged by oil were made with a view to using the data in a land damage suit. There is plenty of evidence of the killing effect of crude oil when in contact with growing plants, but the writer was unable to get data on the damaging effect of varying amounts of crude oil which had been incorporated in the soil from any cause, and the following year this soil was prepared for growing a crop. It was claimed by one witness in the course of the damage suit that the soil was "killed" by the oil, whatever that may mean. It might be supposed the killing referred to meant destroying bacterial life in the soil and making it useless in further crop production.

VEGETATION EXPERIMENTS

Since no data bearing directly on this problem were available, it was thought to be worth while to carry on some vegetation tests to determine how much oil may be incorporated with the soil and not render it useless for crop production or kill all the bacterial life in the soil.

Plan of experiment

Unglazed earthen pots, holding about one gallon, were filled (8.8 pounds) with air-dry, sandy peat soil similar to that under litigation, and tests were run in duplicate. The oil was thoroughly mixed with the soil, only 5 drops being added at a time, and then well stirred. The soil was then wet with water containing soybean bacteria. After standing for 2 days soybean seeds were planted. Table 1 gives some details of their growth and maturity.

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TABLE 1

Growth of soybeans in soil containing varying amounts of crude oil

POT NUMBER	OIL PER GALLON OF SOIL	TOTAL NUMBER OF PODS PRODUCED	TOTAL WEIGHT OF PODS	AVERAGE WEIGHT PER POD	NUMBER OF STALKS	NODULES PER STALK	DRY WEIGHT OF 3 STALKS	PER CENT OF OIL ADDED TO SOIL	OIL ADDED PER ACRE (2,000,000 LBS.)
	cc.		*gm.*	*gm.*			*gm.*		*lbs.*
1	Blank	40	14.0	0.35	3	25	25	0	0
2	5	39	16.0	0.41	3	20	26	0.12	2,200
3	10	32	12.1	0.38	3	30	24	0.25	4,400
4	20	33	12.5	0.38	3	28	24	0.50	9,000
5	30	84	38.0	0.45	3	108	61	0.75	13,400
6	40	35	14.0	0.40	3	48	26	1.00	18,000
7	50	33	12.5	0.38	3	48	24	1.25	22,400
8	60	32	13.0	0.41	3	96	23	1.50	27,000
9	70	25	8.0	0.32	3	29	14	1.75	31,400
10	80	18	4.5	0.25	3	23	15	2.00	36,000
11	90	31	10.0	0.32	3	32	26	2.25	40,400
12	100	15	5.0	0.33	3	12	9	2.50	45,000
13	120	15	4.3	0.29	3	30	9	3.00	54,000
14	160	3	0.4	0.13	3	7	8	4.00	72,000

DISCUSSION

It will be noted from the table that the growth of soybeans was apparently improved through the addition of small amounts of oil (30 cc. per gallon, 0.75 per cent) and that rather large amounts may be mixed with the soil (160 cc. per gallon, 4.0 per cent) before the soybean plant succumbs to the oil treatment. The damage seems to be due in part to the plant's inability to secure water rapidly enough to meet its needs.

It would appear from the table that a small amount of oil is even desirable in nodule development in the soybean plant as compared with the check pots, and where the amount of oil was increased to the extent of damaging the plant, there was still some nodule formation.

ACID SOILS AND THE TOXICITY OF MANGANESE

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A study of the peculiar behavior of certain plots on the Alabama Agricultural Experiment Station Farm led the writer to conclude that soluble manganese produced by the action of nitrogenous fertilizers was the cause of the toxicity of these soils, and of their water extracts. The results on which this conclusion was based were published in Bulletin 201 of the Alabama Agriculture Experiment Station.

Further studies on these plot soils and on others from various places in Alabama indicate that the earlier conclusion is untenable, since the addition of manganese carbonate to such toxic extracts has produced conditions favorable to the growth of seedling pea roots in every instance. Acid soils when incubated with dried blood and manganese carbonate gave extracts which contained more soluble manganese than when incubated with dried blood alone, but were not nearly as toxic. The injury resulting from large amounts of manganese, under these conditions, is more apparent on the leaves than on the roots of seedlings; the leaves being bleached and abnormal in shape, whereas the roots make nearly a normal growth. Moderate amounts of soluble manganese in extracts of soils incubated with dried blood and manganese carbonate caused no apparent injury to either roots or tops of pea seedlings.

The accumulated evidence at hand indicates that the toxicity observed in certain soils and soil extracts, after incubation with a nitrogenous fertilizer, is possibly due to uncombined acid, or more probably to readily hydrolyzable salts. Hydrogen-ion determinations made on such toxic extracts showed that in all cases the H-ion concentration was relatively high. Further details are reserved for a later publication.